

# VOICE COIL

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Spotlight

## A FINE Circle Hardware/Software Tutorial Part 1 — The Design

By Vance Dickason and Peter Larsen

Some years ago, I had a group of CAD programs and analyzers that were employed by myself and the transducer engineers with whom I worked (primarily Patrick Turnmire) to develop complete system designs including the transducers, the enclosures, and the crossover networks. This was comprised of the LinearX LMS analyzer, LinearX LEAP 4, LEAP 5 Enclosure Shop, and Crossover Shop CAD software, Redrock Acoustics RevSpeaD and SpeaD transducer software, and Comsol FEA simulation software. Except for Comsol, all these programs and hardware are no longer available. However, I've been impressed that Peter Larsen, over the years, has produced a group of programs and measurement hardware that accomplished all the various tasks required for a complete system design, the transducers, the enclosures, and passive crossover designs. His company, Loudsoft refers to this collection of hardware and software as the "FINE Circle" of design. The FINE Circle (**Figure 1**) includes the FINE R+D analyzer, FINEMotor, FINESuspension, and FINE Cone transducer software, and FINEBox enclosure design software, FINE X-over, and FINE DSP and network design software.

Given all this, I asked Peter to develop a tutorial for the design of a complete loudspeaker from transducer to final

Figure 1: The FINE Circle of loudspeaker design hardware/software from Loudsoft



product. The target design will be a two-way speaker with a 6.5" woofer and a 1" dome tweeter. The following content was contributed by Peter Larsen.

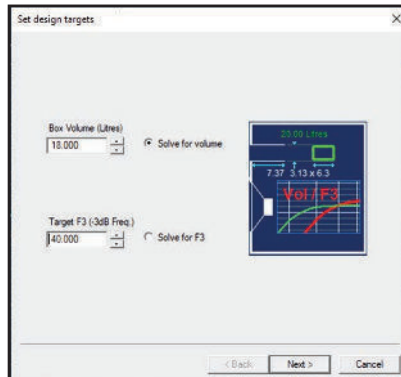


Figure 2: Inverse FINEBox set to 18-liter box volume target

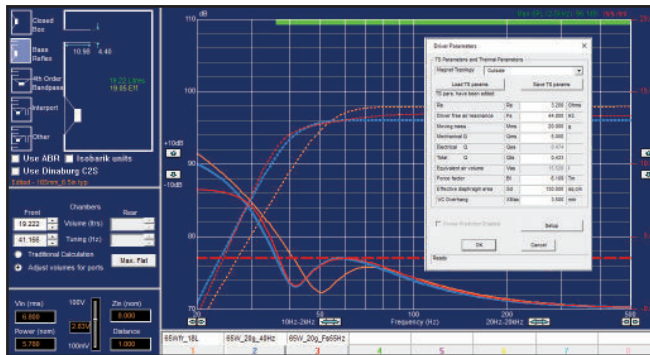


Figure 3: Initial and optimized low-frequency responses for the 18-liter bass reflex box

The basic two-way Design Target is:

- 18-liter bass reflex box
- Two-way design
- 6.5" woofer
- 1" dome tweeter
- Frequency range: ~40Hz-30kHz

For the 6.5" woofer design, the following programs were utilized:

- FINEBox initial simulation to define target Thiele-Small (T-S) data
- FINECone Acoustical Cone and initial surround design
- FINEMotor Motor Design
- FINESuspension Design of surround and spider
- FINE R+D analyzer for confirming woofer measurements

### FINEBox Initial Simulation to Define Target Thiele-Small Data

After starting FINEBox, I selected the "Inverse FINEBox" program. As a design target, I input 18 liters and "Solve for Volume," as shown in **Figure 2**. From the drop-down list of default drivers in all sizes, I selected "165mm\_6.5in typ." Now we have enough data to start box simulations. The target T-S parameters are shown in **Figure 3**. The result of the initial simulation produced the brown dashed curve #1 shown in Figure 3. It gives ~98dB SPL with a -3db point at 50Hz, with 5.9V/4.33W input for getting Xmax (~3mm).

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To reach the low-frequency target, we needed more moving mass. After increasing the moving mass to 20g and slightly increasing Xmax, I ran the Inverse FINEBox again, this time optimizing for F3=40Hz. This is shown as the blue dashed curve #2, which has -3dB at 40Hz. The target T-S data is shown in the grey window of **Figure 4**.

The red curve #3 shown in Figure 3 is a version with higher Fs, tuned slightly lower for reducing voice coil travel below 40Hz (see the solid red curve, lower left). The slight downward slope toward 40Hz helps to get a flat response

TS Parameters and Thermal Parameters			
Magnet Topology: Outside			
Load TS params Save TS params			
TS pars. have been edited			
Re	Re	3.200	Ohms
Driver free air resonance	Fs	44.000	Hz
Moving mass	Mms	20.000	g
Mechanical Q	Qms	5.000	
Electrical Q	Qes	0.456	
Total Q	Qts	0.418	
Equivalent air volume	Vas	15.528	l
Force factor	Bl	6.228	Tm
Effective diaphragm area	Sd	130.000	sq.cm
VC Overhang	XMax	3.500	mm

Figure 4: Optimized T-S parameters for obtaining F3=40Hz (blue curve #2)

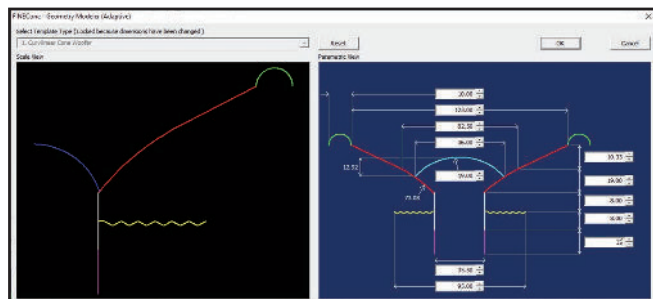


Figure 5: FINECone Geometry Modeler template with user input

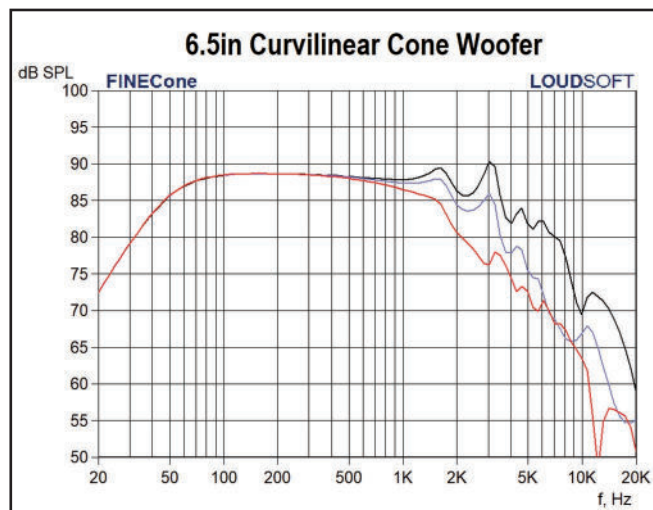


Figure 6: Calculated 0°/30°/60° frequency responses for the initial 6.5" woofer

in a room with wall and floor reflections (room gain from boundary loading).

## Cone/Surround Design

In this next step I used FINECone to design the 6.5" cone, surround, and dust cap. After first selecting the Geometry Modeler, I then chose the Curvilinear Cone Woofer template, shown in **Figure 5**. Here we can simply insert the dimensions we want, while watching the actual geometry be continuously updated at left.

My 6.5" frame has a clamping ID of 143mm. Setting 10mm as initial surround diameter, the cone diameter then should be set to 123mm. After choosing a deep curvilinear cone, I specified a small and tall dust cap, for preventing dust cap break-up following my previous experiences. The Finite Element Model (FEM) will be automatically created from the Geometry Modeler.

FINECone automatically assigned typical values for the thickness of the cone, the surround, and the dust cap. In addition, the cone and dust cap materials were defined as DKM N-paper. The surround was a typical rubber type chosen from the database, plus a typical cotton spider with medium stiffness. **Figure 6** depicts the calculated 0°/30°/60° frequency response of the 6.5" woofer with the given dimensions and materials.

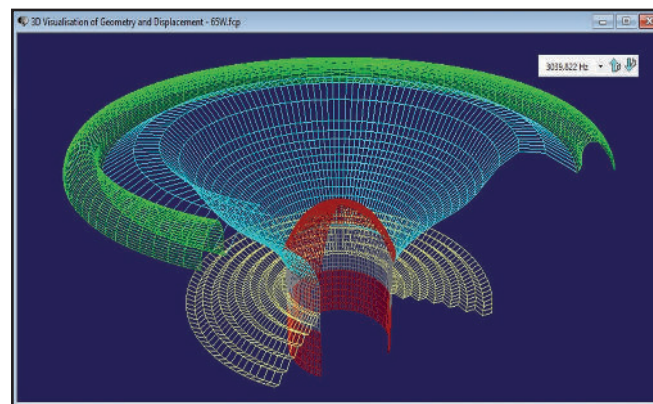


Figure 7: Cone break-up mode at 3039Hz

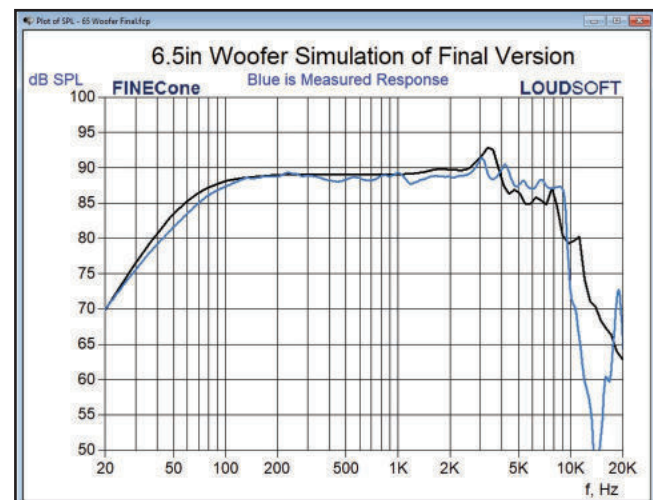


Figure 8: FINECone calculated final frequency response compared to measured sample

The calculated frequency response is not flat and has a couple of peaks  $\sim 1700\text{Hz}$  and  $\sim 3100\text{Hz}$ . At  $1739\text{Hz}$ , the cone edge and inside surround edge bends down and almost in opposite phase of the cone. **Figure 7** shows the calculated displacement at the 3039 mode, which is the first cone break-up mode in the outer part of the cone.

**Figure 8** shows the final response (black curve) of the 6.5" woofer with the optimized cone and the surround plus dust cap. To suppress the cone/surround mode at  $1739\text{Hz}$ , the surround thickness was increased from  $0.35\text{mm}$  to  $0.6\text{mm}$ . This was more effective than a thicker cone edge. In addition, the cone material was selected from the database as a talc-filled PP cone with high damping. The

new response, illustrated in Figure 8, is now fairly flat up to the  $3039\text{Hz}$  cone mode. The blue curve is the measured response of the actual 6.5" woofer using the FINE R+D analyzer. The calculated FINECone response is quite close to the measured results.

## 6.5" Woofer Motor Design

The initial FINEMotor simulation uses a  $90\text{mm} \times 45\text{mm} \times 15\text{mm}$  Y30 ferrite magnet and cone/surround/dust cap mass from FINECone. In the Direct FEM window, which performs the magnetic Finite Element calculation, a 3mm bumped back plate was chosen, and the  $\text{Bl}(\text{x})$  curve becomes symmetric after extending the pole piece by 3mm. However, the  $\text{Bl}$  is still lower than the target

To get high  $\text{Bl}$  in a tight air gap, I chose a one-layer edge-wound voice coil. After focusing the B-flux with undercuts below and above the top plate, we get a nice solution,

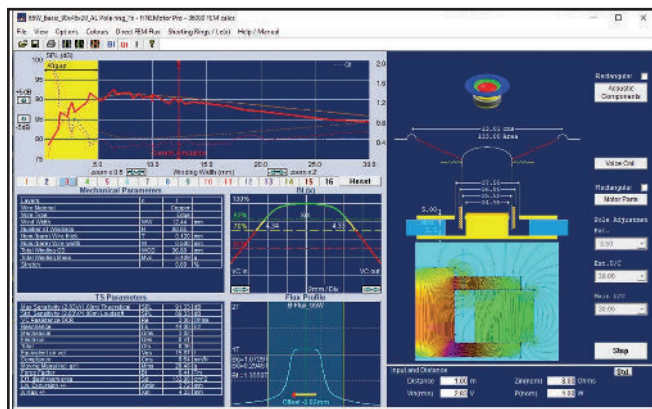


Figure 9: Final 6.5" woofer motor with one-layer voice coil and optimized pole geometry

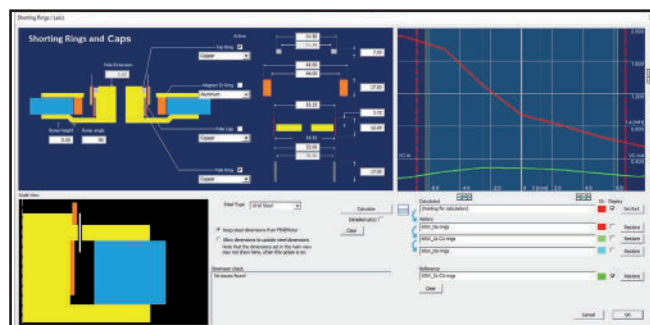


Figure 10: Symmetrical  $\text{Le}(\text{x})$  using two optimized copper rings

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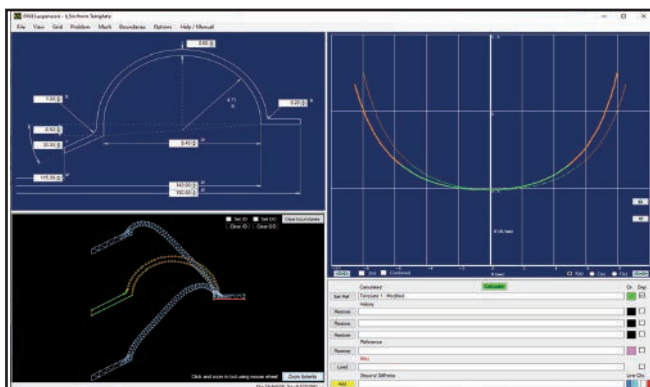


Figure 11: Nonlinear FEA surround calculation from Template 1

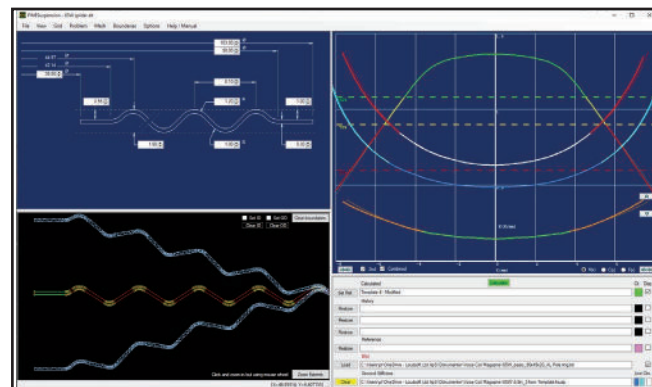


Figure 12: This is the FINESuspension main page used to calculate a suitable spider.

which is close to the target. However, the  $Q_{ts}=0.47$  is still too high. **Figure 9** depicts the final solution (#3), using a larger 90mm×45mm×20mm Y30 magnet, where no bump is necessary due to the thicker magnet.

Now let's look at the voice coil induction  $Le(x)$ . **Figure 10** displays the screen for Shorting Rings and Caps/  $Le(x)$  in FINEMotor, where we can insert rings in various places and in different materials and calculate the voice coil induction  $le(x)$  using the FEA engine. A standard copper ring under the top plate will lower  $Le(x)$ , but it is most effective at low voice coil positions (negative  $x$ ).

To prevent DC-offset while playing, the  $Le(x)$  curve must be symmetric around the Y-axis, which is seldom possible using only one ring. In Figure 10, I have therefore inserted two copper rings below and above the top plate. They are

different in thickness and length, causing the resulting  $Le(x)$  curve (green) to be quite symmetric. The red curve shows  $Le(x)$  without any rings, and the improvement of  $Le(x)$  is remarkable.

## Fine Tuning the Suspension Design

From FINECone, we received a preliminary design for the surround. Next, I optimized the large signal parameters in the nonlinear domain using FINESuspension. I began with Half-Roll Template 1 and input the dimensions I already knew—the roll diameter (10mm) and 0.6mm thickness, and clamping ID 143mm, as shown in **Figure 11**. The  $Km(x)$  stiffness curve was calculated using Non-Linear FEA and is nicely U-shaped, however not symmetric (observed from the dashed mirror curve).

Since the previous curve showed less upward movement capability, I compensated by moving the cone flange down. The calculated  $Km(x)$  curve was now fully symmetric. The green range indicated the usable  $\pm 5.5\text{mm}$  range (per IEC62458), which is OK. This is shown as the lower curve in **Figure 12**. I also used FINESuspension to calculate a suitable spider, as shown in Figure 12. Using Spider Template 4, I input the known dimensions of the inner diameter (ID) and outer diameter (OD). Playing with the wavelength, I found 5.7mm (between wave tops) produced a spider with a nice flat area close to the voice coil. That would be covered with stiff glue, which I define by the green fixture lines.

The calculated  $Km(x)$  curve is good, but not symmetric because the spider has less downward movement capability. I chose to compensate for that by moving the voice coil flange up and the outside down. The  $Km(x)$  spider curve was now symmetric (the lower curve shown in Figure 11). The previous surround  $Km(x)$  curve was imported as the middle blue curve.

Above that, the  $Km(x)$  of the combined surround + Spider was shown as the Red/White curve, having a working range of  $\pm 5\text{mm}$  (per IEC62458). Ideally, this should be comparable to the operating range of  $Bl(x)$ . For this reason, I imported  $Bl(x)$  from FINEMotor as the upper curve. The green range was almost the same, ensuring enough stiffness above  $X_{max}$ . This provides very high stability. Stay tuned for Part 2! **VC**