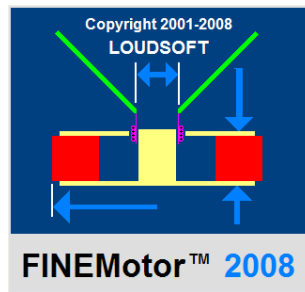
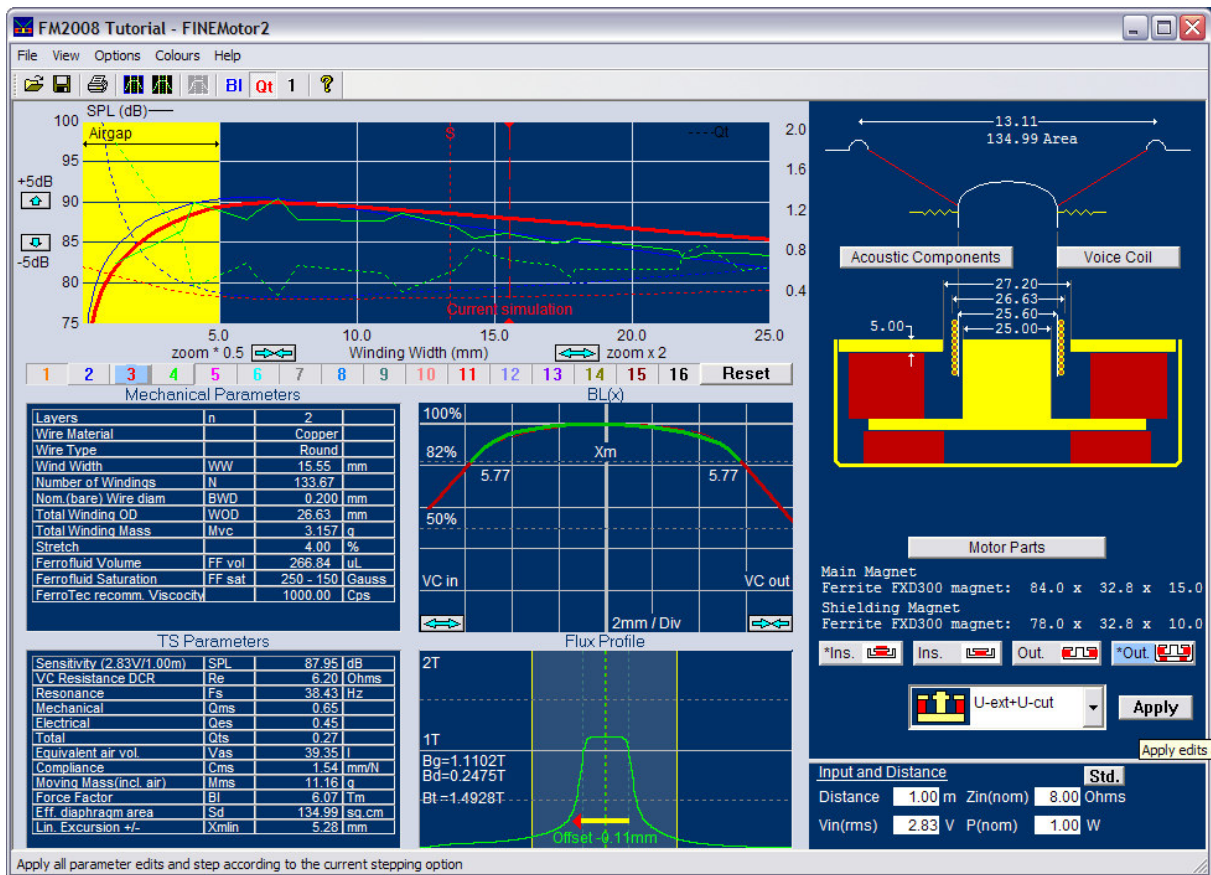


FINEMotor™



Magnet System & Voice Coil
Design Program

TUTORIAL



The FINEMotor program is ideal for simulating and designing the magnet system and voice coil for any kind of loudspeaker driver. This includes not only woofers and domes but also telephone receivers and headphones etc.

6.5" Woofer Design

Start FINEMotor and select "New" or _Default.fm3. We will try to use an existing voice coil with Kapton former and winding width of 9.75mm and VCID= 25.60mm. Press the "Voice Coil" button:

The 'Voice Coil' dialog box contains the following settings:

- Wire Type: Round wire
- Wire Material: Copper
- Former Material: Kapton
- Note: Changing former material will adjust Qms
- Voice Coil Resistance DCR: Re 6.20 Ohms
- Voice Coil Inside Diameter: VCID 25.6 mm
- Number of Layers: n 2
- Twin Coil:
- Voice Coil Former Thickness: 0.050 mm
- Wire Stretch: 4 %

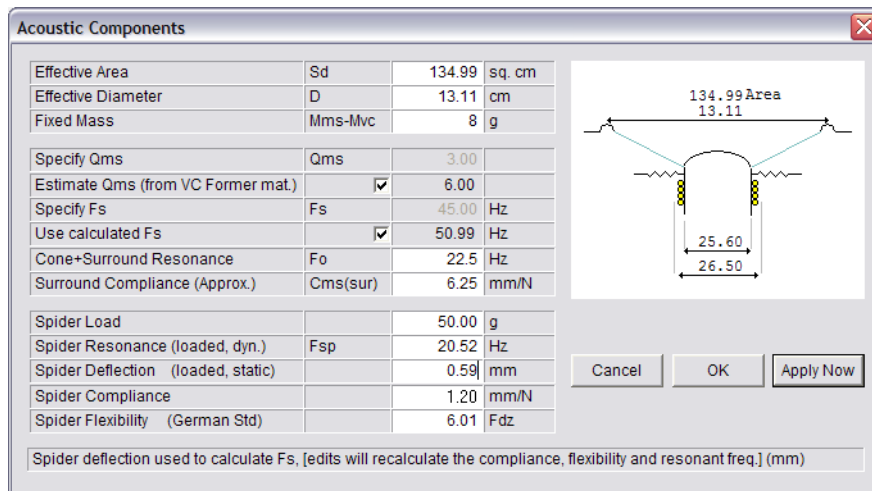
Buttons: Cancel, OK, Apply Now

Accept edits and apply to the current simulation

We have selected a 2 layer round wire copper voice coil and set $R_e=6.2$ ohms, plus set Kapton as Former Material (Use the Kapton setting for all non-conducting VC formers). Note "Wire Stretch" is set to 4% to match our existing voice coil. Press "Apply Now". Click on the upper left window and mouse drag to get close to the 9.75mm winding width. "Mechanical Parameters" shows the winding width to be 9.69mm using 0.17mm wire, which is really close.

Note: In a nominal 8 ohms system you can often go down to DCR= 5.5 ohms (or even lower) and still keep the minimum impedance of 6.4 ohms. This is because the min. impedance (Z_{min}) is normally at least 0.5 ohms higher than DCR, and the inductor in the cross-over normally has a resistance (R_L) of 0.3-0.5 ohms or more. – Likewise a nominal 4 ohms system can use a DCR of 2.5-3 ohms or lower while keeping the min. 3.2 ohms impedance.

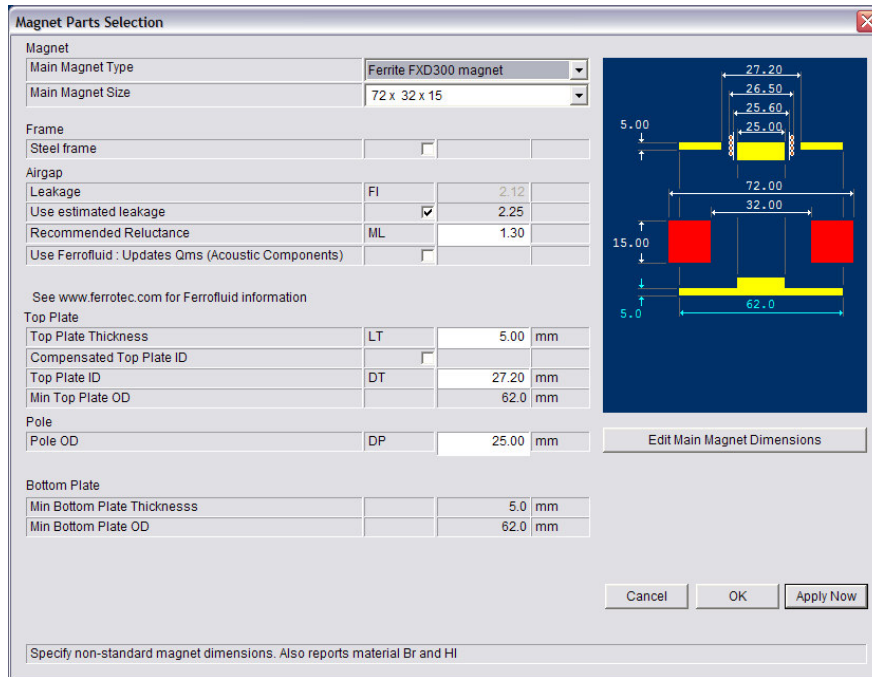
Press "Acoustic Components" and will get you this dialogue window:



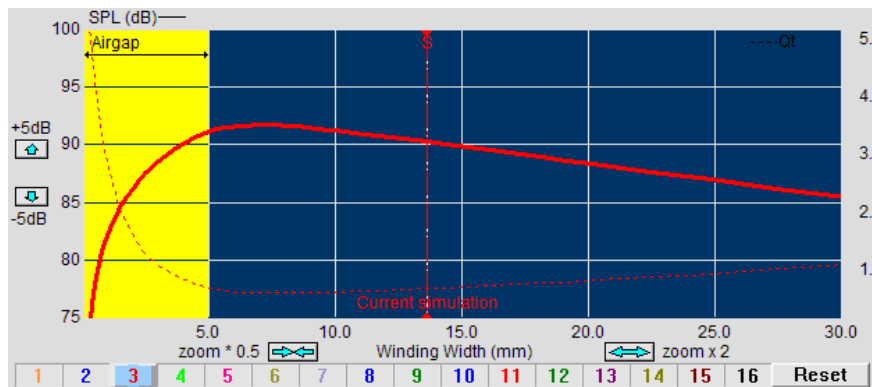
We will input the diameter $D=13.11$ cm (including half surround on each side) to get the cone area (S_d) automatically calculated. Next we need the fixed mass, which is the total moving mass except the voice coil winding. This equals: half (active) surround + cone + dust cap + VC former + half spider + glues + air load. We have weighed that to be 8 grams. We had selected a Kapton voice Coil former and see that the mechanical Q is estimated to $Q_{ms}=6$.

Since we don't know F_s we will have FINEMotor to calculate it for us by clicking in the box "Use calculated F_s ". Our cone with surround has a resonance (Cone-) F_o of 22.5 Hz, which we input and see that the surround compliance is already calculated to 6.25 mm/N. We want to use an existing spider with a deflection of 0.59mm (for 50 g load) but we see that this gives F_s of 50.99 Hz, which is too high. Therefore we should change the spider deflection to 1.0, which gives acceptable F_s of 41.31Hz.

Finally we will take a look at the magnet system. Press "Motor Parts" and make sure "Use estimated leakage is checked [x]":



A 70x32x15 FXD300 ferrite magnet is chosen (Chinese Magnets are also available) plus a 27.20diam x 5 mm top plate and a pole piece used elsewhere. Here you can also specify a steel frame, which will lower the BL due to increased leakage, but leave that unchecked for now. (Leave the reluctance ML=1.30 unless you have better info). Apply and go to the upper left diagram:




This is the main display showing a curve for all possible Voice Coils satisfying the criteria we have defined previously. Short winding VC's are to the left and increasing Winding Widths (WW) towards the right side, in this case is shown up to 30mm WW. The vertical dashed line indicates the current simulation. Try holding the left mouse button down and drag left and right, simulating longer windings (WW) at right and shorter on the left side. The yellow area indicates the air gap (here 5mm). So we see under-hung VC's in the yellow area and over-hung VC's in the right blue area. The Thiele/Small Parameters are simultaneously calculated below in all cases.

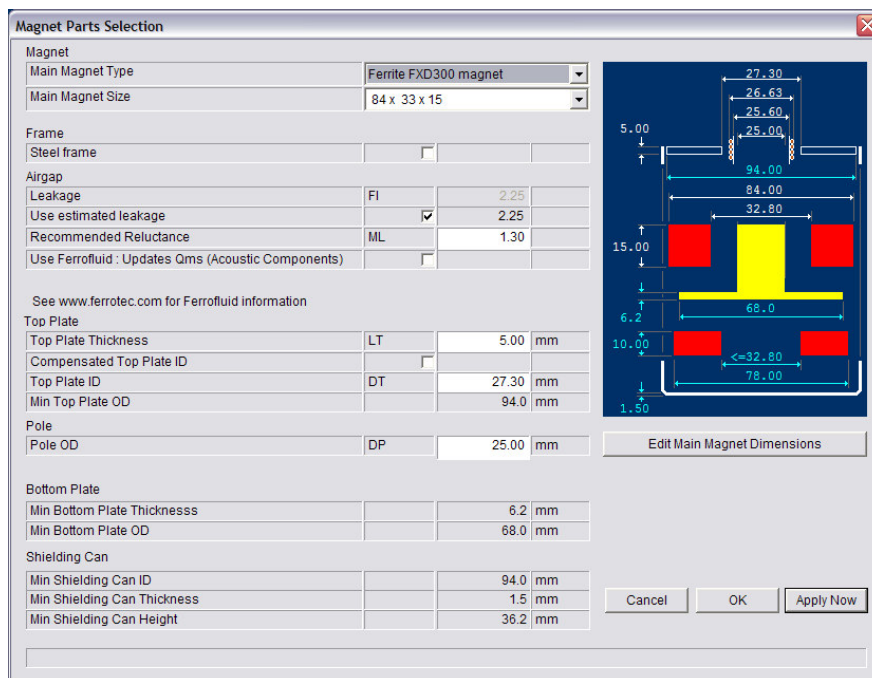
For the ~10mm winding width we get a Qts of 0.45 and (linear) Xmax (Xmlin) of 2.35mm. That Qts is too high for our bass reflex application, where we need a Qts of ~0.30-0.35. Therefore let us try a larger magnet: In "Motor Parts" press the down arrow for Magnet Size and select 84x33x15mm. Apply now:

Qts is now 0.29, due to an increase in BL from 5.62 to 7.14Tm. This solution is useable, but we can even accept a longer WW of say 15.5mm giving linear Xmax=5.28 (Xmlin), while keeping a low Qts=0.33. Actually we should also find the best resting (0-) position for the VC, so try to drag (and use mouse wheel) the VC 0.53mm to the left (down into the motor), and we get a more symmetrical BL(x) curve. (See more later on).

Note: Using this magnet, the back plate thickness must be increased from 5 to 6.3mm, which is shown on the sketch.

The only problem with that solution is that we actually need this woofer to be magnetically shielded. In FINEMotor that is quite easy: Press **Out. Shld.**  and we get a shielded motor with the same TS parameters! All dimensions of the shielding can and the best back plate are given in "Motor Parts".

Note that the back plate diameter should be reduced from 74 to 68mm, to give the best shielding and BL.



You can find this solution saved as 6,5wfr1.fm3 in the examples on the install CD and also in C:\Program Files\LoudSoft\FINEMotor20\Examples.

However a different approach is trying a 4-layer Voice Coil (in "Voice coil") instead of a larger magnet. Go to the Motor Parts and reselect the 72x32x15mm magnet again. A 4-layer Voice Coil, however, will need a thicker wire and therefore we have to modify the air gap. How can we control the change of the magnet field and TS parameters?

The solution is to check the box "Compensated Top Plate ID" [x] (in "Motor Parts"), because that will keep a constant voice coil clearance and at the same time recalculate the magnet gap field! Enter 0.35 for clearance and then OK. Then open "Voice Coil" and select 4-layers. Apply Now.

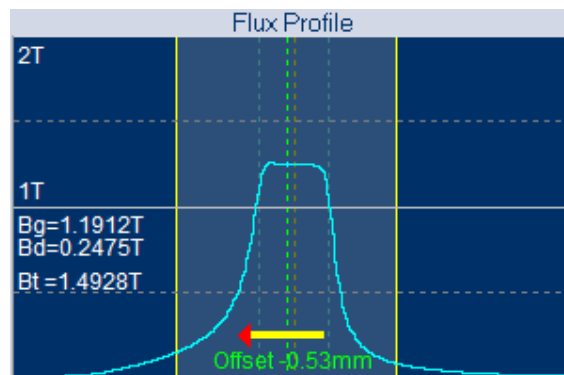
On the curve select a winding width close to 10mm and we see Qts is now 0.28! Therefore we can select a winding width of ~14.5mm and still get a low Qts of 0.34, and with an Xmlin of 4.78mm. Note that the Top Plate ID increased automatically to keep the preset clearance and Fs (calculated) is lower due to the higher voice coil mass. This version is saved as 6,5wfr2.fm3

From FINEMotor 2008, you can directly simulate the non-linearity of BL as a function of the Voice Coil excursion (x). This is displayed as the BL(x) curve, which in this case is non-symmetrical left/right (= in/out of the motor). The dashed red line is the mirror curve of the BL(x) curve, which helps to decide if the BL(x) curve is symmetrical. In that case the two curves would overlap.



The BL(x) curve shows how BL is varying with in/out excursion (x) of the Voice Coil

Going back to the first two layer solution the found TS parameters were OK, but the BL(x) curve was not symmetrical (without VC offset), since BL is higher when the Voice Coil (VC) is inside the motor. That is because of the higher leakage caused by the cylindrical and flat pole piece in level with the top plate. The flux in the lower screen shows that there is more magnetic flux below the air gap, because the curve is higher in the left side. The BL(x) curve will change from green to red when BL=82% of the BL at the rest position, so the green curve normally ensures that the distortion is sufficiently low. That also defines the acceptable X_{max} , namely $-X_m$ (in) and $+X_m$ (out). In this case X_m (in) is 6.10mm and X_m (out) is 5.04mm.

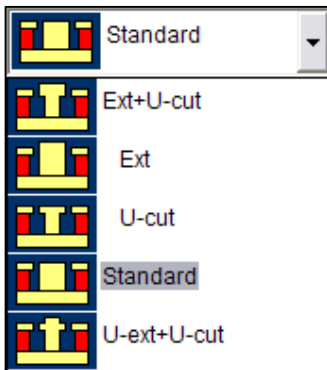


Most of this asymmetry can easily be cured by offsetting the VC so the mirror curve overlays the BL(x) curve. This is done by dragging the yellow arrow in the “Flux Profile” window with the left mouse button. An offset of -0.53mm is sufficient to provide good symmetry for large excursions (x). Now we get both $-X_m$ (in) and $+X_m$ (out) = 5.54mm, which is even slightly larger than the linear (X_{max}) X_{mlin} =5.28mm, defined by the VC over-hang.

However the BL(x) is still not perfect. Ideally the green centre part should be flat and continue with a sharp corner to the red slopes.

Fortunately we can change the shape of the BL(x) curve by modifying the pole piece. Press the drop down box (see below), and a selection of Pole Geometries becomes available.

Pole Geometries



[U-cut] Undercutting of the pole piece below the top plate (the undercut may be 1-2mm, usually comparable to the air gap slit (Air gap = $(\text{Top plate diameter} - \text{Pole diameter})/2$). (*))

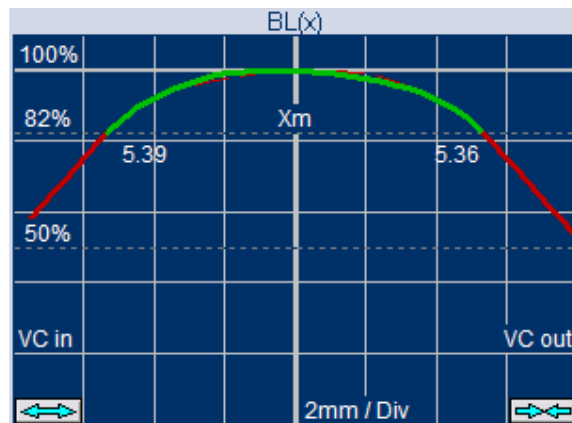
[Ext] Extended pole piece, by approx. half of the top plate thickness.

[Ext + U-cut] A combination of the two above.

[U-ext + U-cut] As the previous, but where the extended pole piece part is also undercut to the same diameter as before.

**Note: Be careful with smaller VC diameters as the pole piece steel may saturate, because the total flux ($B \times \text{area}$) goes through the pole piece. (Design consulting is available from www.loudsoft.com)*

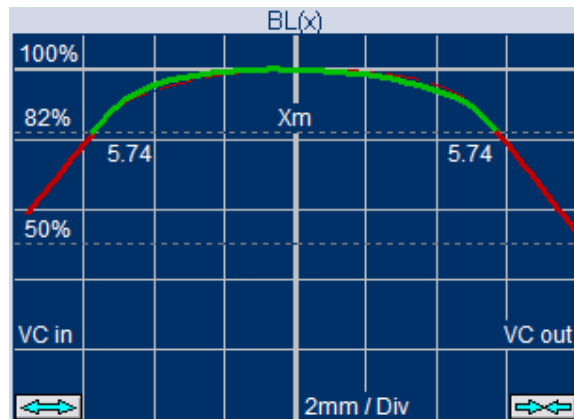
First let us try to extend the pole piece by selecting [Ext] from the Pole Geometry drop down list. That gives the following BL(x) curve (no VC offset):



This BL(x) curve is almost symmetrical, which is a considerable improvement. However the green centre part is not that flat. The X_m is ~ 5.36 mm in both directions. This version is saved as 6,5wfr3.fm3

The best solution is found using the last Pole Geometry [U-ext + U-cut]. This concentrates more flux in the air gap due to the undercuts both above and under the air gap. The resulting BL(x) curve is close to perfect being very symmetrical and having a more flat green centre curve up to X_{max} , and X_m is increased to 5.74mm in both directions.

The penalty however, is a slightly lower BL giving a higher Q_{ts} due to reduced leakage above and under the air gap. This version is saved as 6,5wfr4.fm3




Finally the user may export the FINEMotor *.fm3 files into FINEBox to check the performance in the actual box. That is the very best way to decide if the found solution(s) in FINEMotor are suitable in your system. (Use “Export as V2 file” to comply with earlier FINEBox versions).

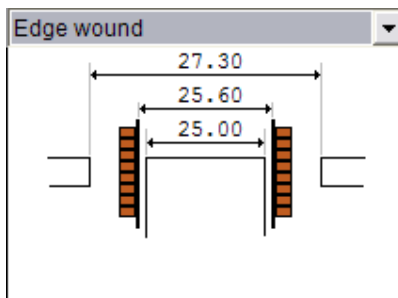
So far we have used the default setting (“Use Estimated Leakage”) for the magnetic leakage FL, because it gives a fast and quite accurate simulation. The most precise may be to import a flux profile from a Magnetic FE program like MagNet, FEMM etc.

Even Magnetic FEA calculations are not always absolutely precise, so you should always verify your simulations by building and measuring prototypes. When you find a difference in BL you can modify the leakage FL (in “motor parts”) to give the most precise simulations results for your similar motors.

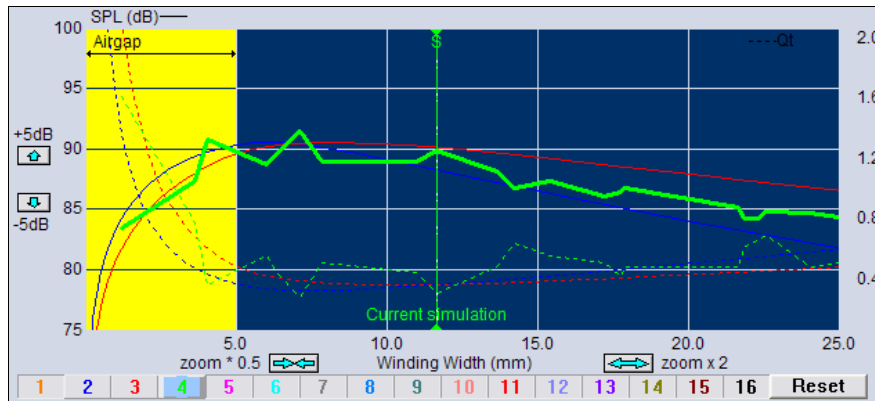
Note: Be sure to measure the TS parameters correctly! Very low level impedance measurements may lead to wrong TS parameters due to non-linearities in the spider. This is especially true for small drivers where the resonance Fs may appear 10-30% higher than when measured at 2.83V! (The FINELab QC system from LOUDSOFT will measure the TS parameters at the same level as the SPL; see www.loudsoft.com)

A flux profile from a Magnetic FEA program may be imported into FINEMotor from the clipboard by CTRL+V or imported as a text file using the  button. The VC may also be offset in that case, but you cannot change the magnet or Pole Geometry, because that is defined in the FEA program.

Let us assume there is a requirement for high power and sensitivity; therefore we will finally consider an edge wound VC. With compensated Top plate ID set, we select 1 layer edge wound wire in “Voice Coil”.



A 1 layer edge-wound VC will have more windings compared to a round wire VC, because the wires are wound on the “side” as shown. The advantage is higher BL, and less inductance, especially compared to a 4-layer VC. In addition the power handling is increased because the wires are closer together and the one layer is better cooled.



The green simulation #4, gives high sensitivity and BL even with the smaller 70x32x15 FXD300 ferrite magnet, therefore giving a low Q_{ts} of 0.24, which may be another possible solution. This version is saved as 6,5wfr5.fm3. The flat wire VC's are normally very difficult to design but FINEMotor helps the design engineer by displaying all solutions in a simple and logical manner. The dashed curve shows Q_{ts} , and #4 simulation is dipping to a very low Q_{ts} . It is also possible to view curves over BL.

But why is the new (green) curve sagged? That is because we see wires with different width/thickness ratio. The shown ~12mm winding width is very good, because the wire is very flat: 0.060x0.65mm.

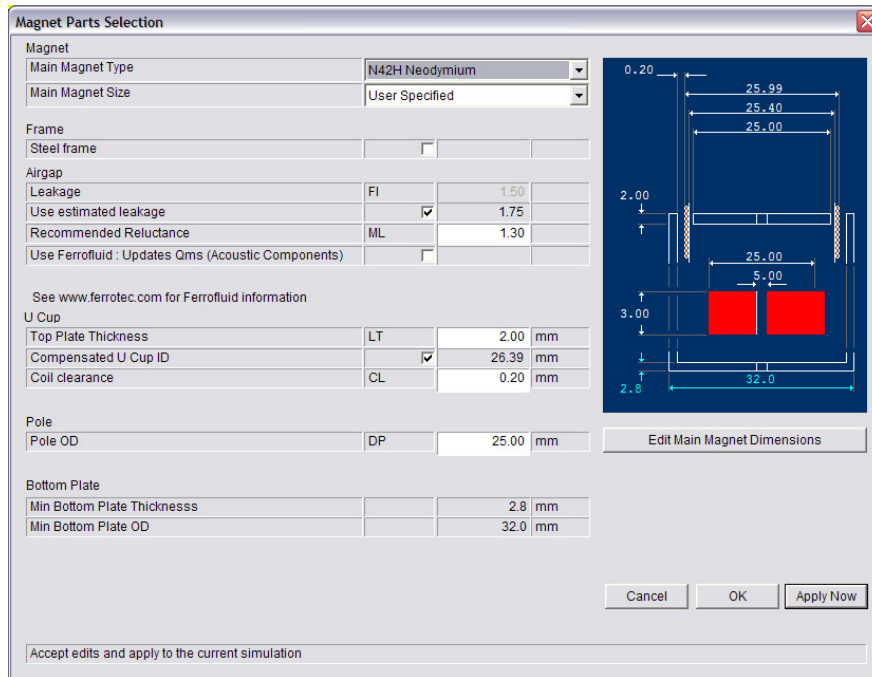
Note: Simulation #1 was turned off by right clicking the corresponding button. Any curve can be shown again by right clicking.

1" Neodymium Dome Tweeter

In this section I want to design a 1-inch dome tweeter using a neodymium magnet disk. Select Inside Motor and input these data in "Acoustic components":

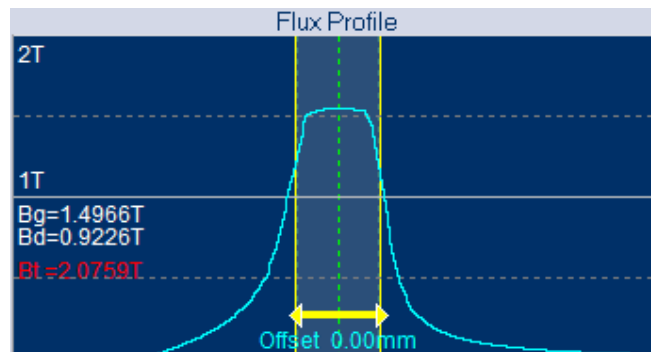
Acoustic Components		
Effective Area	Sd	7.07 sq. cm
Effective Diameter	D	3.00 cm
Fixed Mass	Mms-Mvc	0.14 g
Specify Qms	Qms	3.00
Estimate Qms (from VC Former mat.)	<input checked="" type="checkbox"/>	3.00
Specify Fs	Fs	2000.00 Hz
Use calculated Fs	<input type="checkbox"/>	0.00 Hz
Cone+Surround Resonance	Fo	0.00 Hz
Surround Compliance (Approx.)	Cms(sur)	0.00 mm/N
Spider Load		50.00 g
Spider Resonance (loaded, dyn.)	Fsp	0.00 Hz
Spider Deflection (loaded, static)		0.00 mm
Spider Compliance		0.00 mm/N
Spider Flexibility (German Std)		0.00 Fdz
Sketch of the acoustic components		

The voice coil is 2 layer copper with $R_e=6.3$ ohms. Stretching the winding 4% will get us close to the real voice coil winding width of 2.1mm. Aluminium VC former, gives estimated $Q_{ms}=3$.



Setting the motor data as above will produce an SPL of 88.23 dB using an $\varnothing 25 \times \varnothing 5 \times 3$ mm N42H neo disk. This is the strongest neodymium magnet grade with extended high temperature range. This version is saved as 1in Neo Dome.fm3.

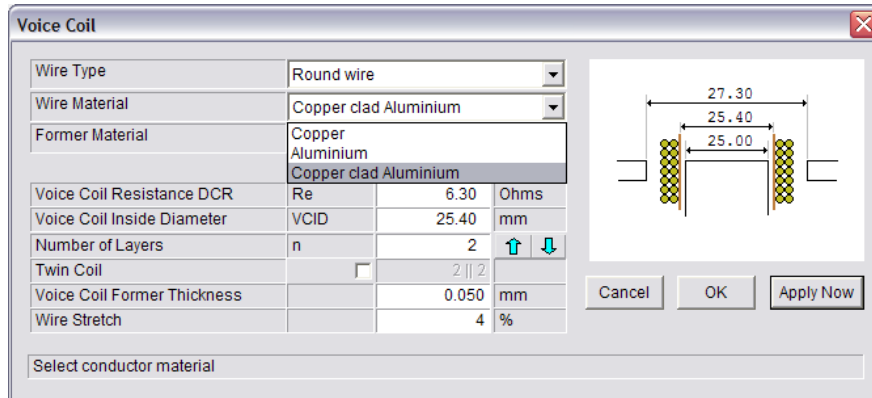
As we still want to increase the sensitivity let us input a thicker 4mm neo disk under “Edit Magnet Dimensions”. However the SPL is now only increased by 0.80 dB to 89.03 dB.



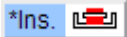
There are two reasons why we do not get much more output by increasing the thickness of the magnet. The above picture shows the flux profile through the air gap, and in the left side we can see $B_g = 1.4966$ T, which is the average B gap flux. Below that is $B_d = 0.9226$ T, which is the operating point of the magnet. That is pretty high for this neodymium material, which is best utilized with a B_d of 0.5-0.8 T, so in this case we don't get much more output by a thicker magnet.

Secondly we see that the top plate is saturated, indicated by $B_t = 2.07$ (Bt is red when over 2T), where Bt is the maximum top plate flux density without saturation. Normal (1010) steel is saturating above 2.0T, but starts to limit already below 1.8T. In this case the SPL loss is around 0.5 dB due to saturation. This increases when Bt is much higher than 2T, so very thin top plates is not a good idea.

Therefore let us try using another wire. After going back to the previous magnet we select a Copper Clad Aluminum (CCAW) wire in “Voice Coil”. This wire is lighter but the (thin) copper coating ensures that it is easy to solder. (Press button “1” to go back to the first simulation, next will be 3).



Selecting the simulation using 0.110 CCAW wire gets us an SPL of 90.23 dB, which is an increase of 2.0 dB. This version is saved as 1in Neo Dome CCAW.fm3.

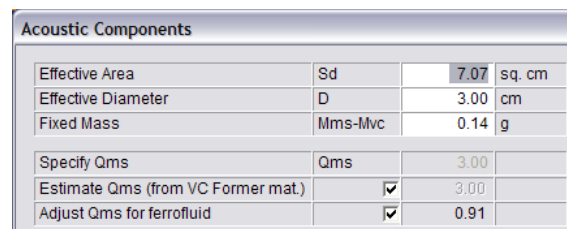
Actually we have one more option to increase sensitivity. Placing a second neodymium disk on top of the top plate will reduce the magnetic stray field, and provide a well shielded motor. An additional benefit is slightly increased sensitivity. Select the “Inside Shielded” button .

The sensitivity has now increased 0.53 dB to 90.85 dB SPL. Saved as 1in Neo Dome SH.fm3.

Finally we have the option to (partly) fill the air gap with magnetic Ferrofluid. The main effect is a much better heat transfer from the Voice Coil winding. Secondly the Ferrofluid will also provide some damping, which depends on the viscosity of the fluid. Fortunately this is also handled by FINEMotor.

Go to “Motor parts” and check the box “Use Ferrofluid: Updates Qms (Acoustic Components)” [x]. A new line appears below: “Ferrofluid Viscosity”. The default input is 1000cPs. (Centipoise). This is a fairly thick Ferrofluid which will provide much mechanical damping i.e. reduce Qms.

This effect can be viewed in the “Acoustic Components” window.



In this case we had used the estimated Qms=3.00. With the 1000cPs Ferrofluid, Qms has reduced to 0.91 in the “Adjust Qms for Ferrofluid” field. This is a considerable damping and causes the Qts to be reduced from 1.02 to 0.58. This version is saved as 1in Neo Dome CCAW SH FF.fm3.

Considering that a tweeter has high excursion at Fs, this damping will lower the excursion and thereby increase the maximum power handling of the system using this tweeter. Furthermore this can reduce the stress on the lead-out tinsels to the VC.

However the Ferrofluid damping can also be used to save components in the crossover. In some cases it is possible to use a 1st order cross-over instead of a 2nd order, saving at least one component (parallel coil). We recommend using the FINE X-over program from www.loudsoft.com to design your cross-over, where you also get the actual power that goes to the tweeter calculated.

Note: It is necessary to provide good venting of the voice coil to avoid splashing of the Ferrofluid! The Ferrofluid will seal the gap, which may cause a higher resonance Fs if not properly designed. LOUDSOFT offers expert consulting regarding this and tweeter optimization in general.

For the most demanding applications a thin Ferrofluid may be the best choice, which means a low cPs value, usually around 100 cPs. These fluids will cause little damping, but still provide essential heat transfer, giving much improved cooling of the Voice Coil, because the Ferrofluid has much better heat conductivity than air, which actually is an isolator. Therefore the VC resistance is rising considerably less giving a much lower power compression.

The FINEBox program from www.loudsoft.com can already simulate the effect of the heat transfer and power compression of drivers, and the coming version will include the effects of the Ferrofluid heat transfer.

It is essential to add a precise amount of Ferrofluid to the air gap; too little gives poor performance (sometimes two resonance peaks around Fs) and too much may splash and increase costs. Fortunately the precise volume is calculated by FINEMotor (3rd last line in the window below):

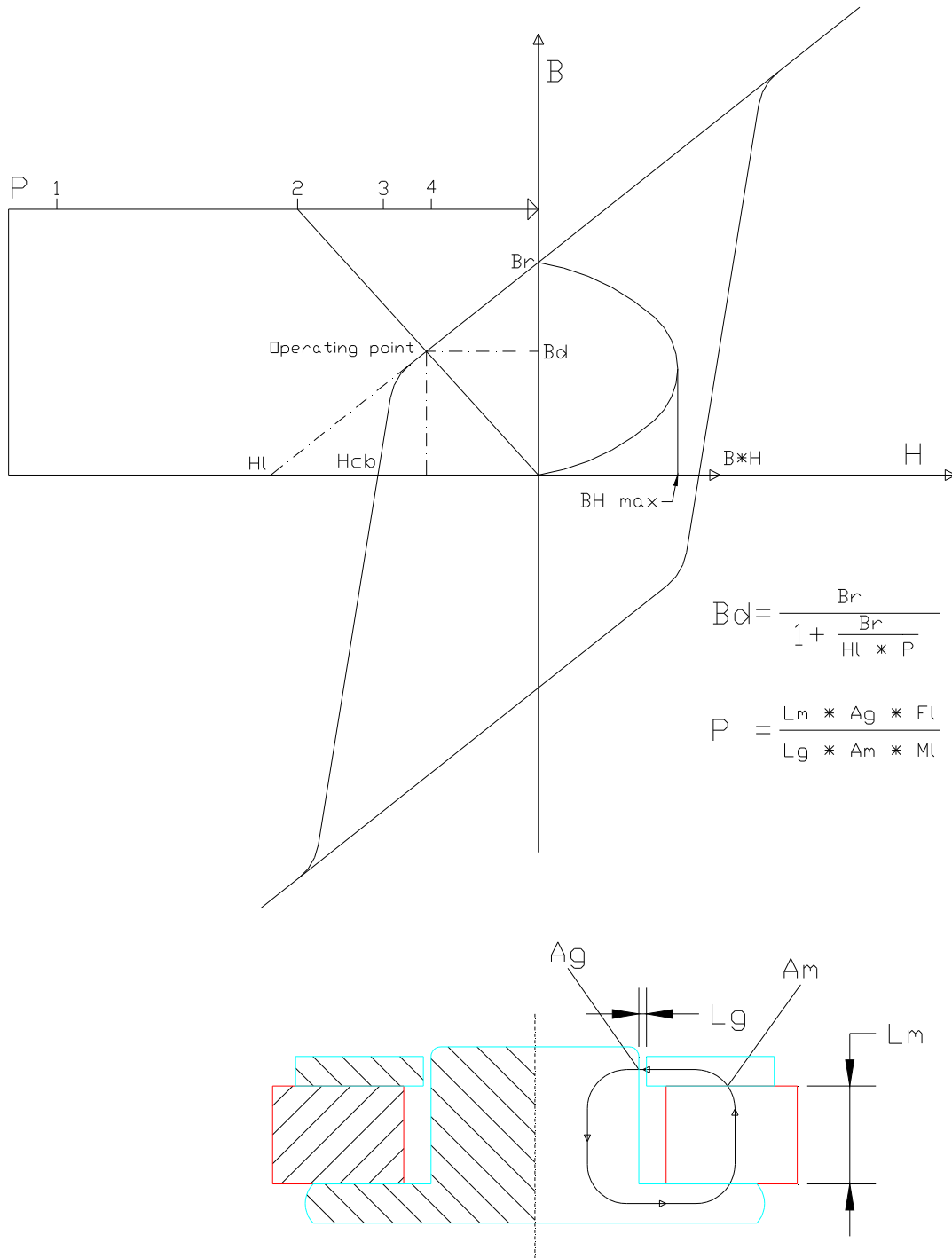
Layers	n	2	
Wire Material		CCAW	
Wire Type		Round	
Wind Width	WW	7.03	mm
Number of Windings	N	70.21	
Nom.(bare) Wire diam	BWD	0.170	mm
Total Winding OD	WOD	26.30	mm
Total Winding Mass	Mvc	0.529	g
Stretch		4.00	%
Ferrofluid Volume	FF vol	72.38	uL
Ferrofluid Saturation	FF sat	200 - 100	Gauss
FerroTec recomm. Viscosity		1000.00	Cps

The necessary Ferrofluid volume is calculated exactly using the criteria from FerroTec, who supplies Ferrofluid. The required Ferrofluid Saturation (Gauss) is also calculated using the actual FINEMotor simulation. It is advised to use the higher number for high excursion and power.

Contact www.ferrotec.com for further info and design advice on Ferrofluid regarding Magnetization, Compatibility with materials and glues etc.

Note: All the above examples are on the FINEMotor CD.

Appendix A. Hysteresis curves and basic formulas



B_d is the working point on the load line (H_l-B_r) according to general magnetic theory.
 P is the Permeance coefficient as defined above, where F_l is the leakage coefficient and M_L is the reluctance coefficient.

Appendix B.

Custom Wire tables

The user can edit a custom round wire table, called DEFROUND.FMW and a custom square (flat) wire table, called DEFSQUAR.FMW. These can be edited with a text editor like notepad.

FINEMotor looks for the files DEFROUND.FMW and DEFSQUAR.FMW in the same directory as the FINEMOTOR.EXE executable at start up (usually C:\Program Files\Loudsoft/FINEMotor20)

1. The content is text and the file must include a new line after the last line.
2. The top 2 lines of each file explain what is in the file and they must not be deleted.
3. You MUST use a . decimal point because the comma separates the values.
4. The values can be in any order, they are sorted on read and as far as we know, duplicates are not a problem.
5. The read values replace the code values, so if you only enter 10 sizes the smaller 10 are the only ones changed; the other sizes are the same.
6. The square wire table contains 4 dimensions IX,IY,OX,OY. It doesn't matter if you get the X's and Y's the other way round, but you MUST have OX > IX and OY > IY
7. The round wire file needs only 2 dimensions ID and OD and you must have OD > ID.

Note! FINEMotor files (Setups) are saved with the actual wire dimensions. If the wire specified in a setup is not in the wire sizes loaded, then you get a warning message that an approximate size has been used.

Appendix C.

Custom Magnet Material tables

The user can edit and create custom Magnet Material table(s), having the extension *.FMM. These can be edited with a text editor like notepad.

FINEMotor looks for files xxxxx.FMM in the same directory as the FINEMOTOR.EXE executable at start up (usually C:\Program Files\Loudsoft/FINEMotor20). See this example:

```
FINEMotorMagnetMaterialFile
Version=1.0
** All lines starting with ** are seen as comments
** The 2 first lines above are required and must NOT be erased or changed.
Parameters
**The next 3 lines must be the name and 2 magnet material parameters:
Name=Y25 Ferrite
Br=3750
Hl=3409
**Note: Br (G) is the Remanence in Gauss (1G=0.0001T)
**Note: Hl (Oe) is the Coercivity in Oersted for B=0 (Extrapolated load line).
**Note: Hl=Br/urec - urec is recoil permeability
** 1[kA/m]=4*pi[Oe]
EndParameters
** Use these lines to add your own comments.
** More lines starting with ** can be added
** Then the list of magnet sizes should follow with no blanks or comment lines.
Sizes : (OD; ID; Length;Name)
72.0; 32.0; 15.0; 72 x 32 x 15
84.0; 32.8; 15.0; 84 x 33 x 15
```