The Future of Micro Speakers

Designing micro speakers for high power and maximum SPL using FINEBox non-linear/high Power design program plus FINECone and FINEMotor.

High quality Hi-Fi loudspeakers used to be large square boxes filled with large woofers, midranges and tweeters. In contrast today's loudspeakers are small and portable and widely used with smart phones.

These small devices require much smaller speaker drives. However when the driver size is reduced much higher demand is put on these transducers regarding cone displacement and input power.

The smaller cone area dictates a lower SPL, which in reality cannot be compensated by increased cone/Voice Coil displacement. In addition the micro speakers used in smart phones and many other portable devices have to be thin, which further limits the output.

Considering that these micro drivers are actually developed from tiny and inexpensive speakers only intended for toys, we begin to understand the challenges for designing and optimizing these micro drivers and systems for high power and maximum SPL.

Micro Loudspeaker System Design

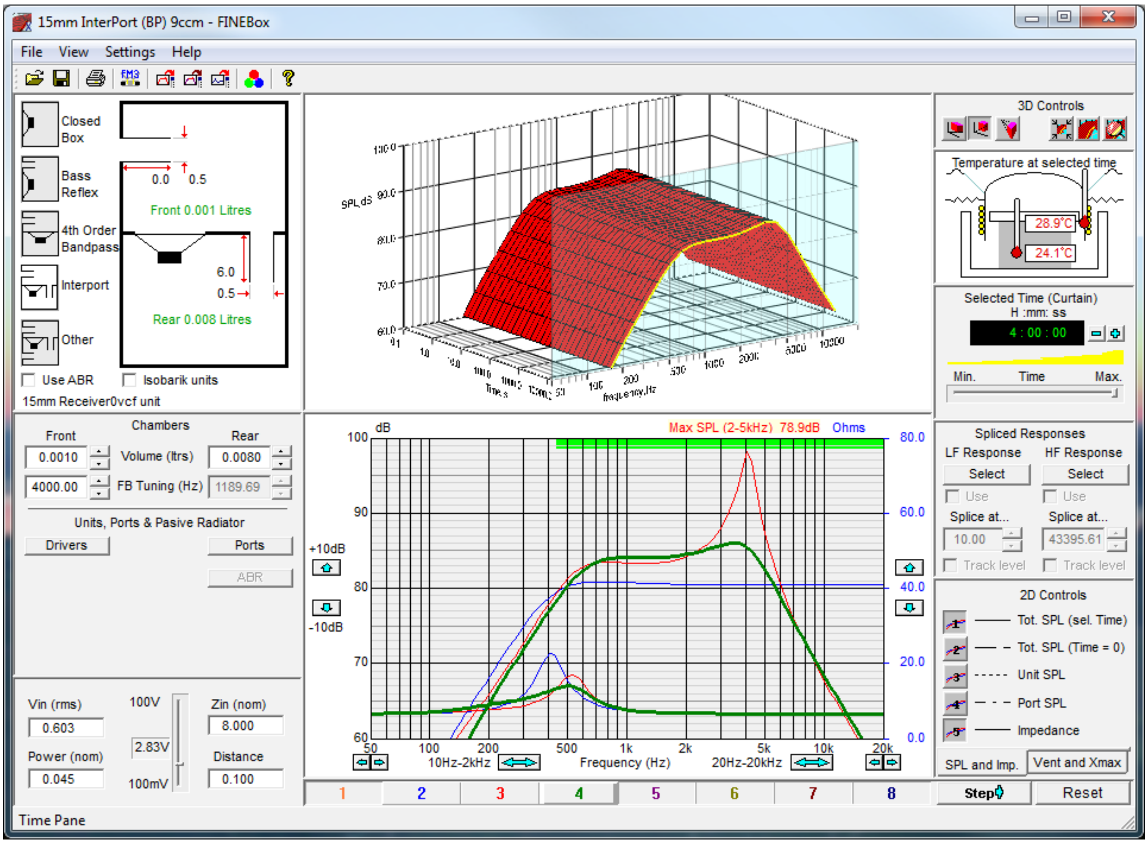
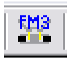


Figure 1 - 15mm micro speaker in closed___/Band pass___/ damped InterPort____

We can use FINEBox to design and optimize the acoustic loading / box volume and tuning of the micro speaker system.

Micro loudspeaker drivers may be designed in FINEMotor and FINECone, and the results can then be imported into FINEBox, where the performance is predicted by simulation.

Now let us start a micro box design by importing a 15mm micro speaker design as a FINEMotor file (with T/S parameters and thermal data) directly into FINEBox by pressing the "Read Unit" button.



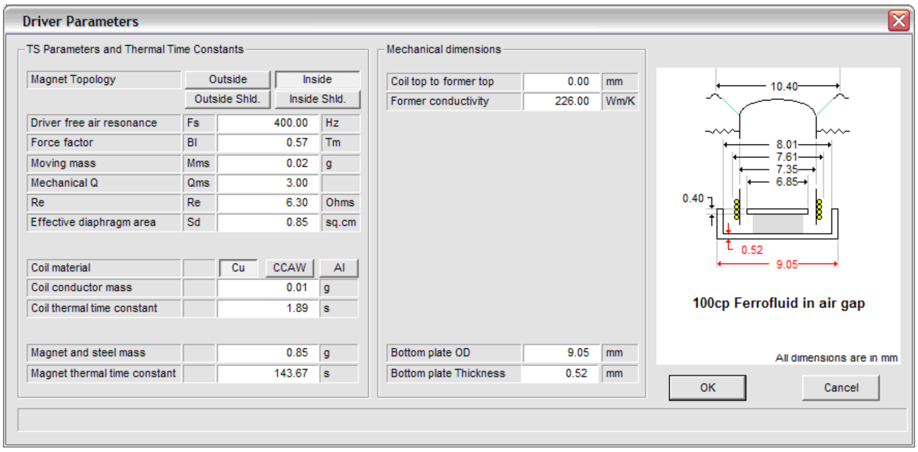


Figure 2 - Complete 15mm micro speaker data imported from FINEMotor

Fig. 2 shows the complete driver data, imported from FINEMotor. The thermal time constants of the Voice Coil (VC) and motor are automatically calculated.

First the 15mm micro speaker/receiver unit is put in a closed box volume of 0.1 L (100ccm) by selecting the upper left button "Closed Box" and adjusting the (Front-) volume to 0.100L by rolling the mouse wheel. This is shown as the blue curve in Fig.1 (Button #2).

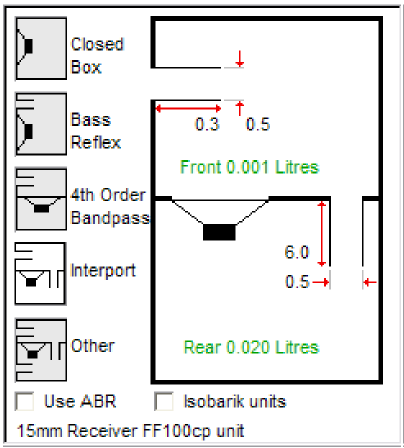


Figure 3 - FINEBox Acoustic Loadings

The blue curve (#2) has an impedance peak close to 400 Hz, which is the resonance Fs. The input voltage was adjusted to give an Xmax excursion of 0.28mm, (= Xmlin: max excursion with Voice Coil still in the gap). This gives a max SPL of 81dB at 0.1m defined by the frequency range indicated by the upper green horizontal line. See also later Fig.6.

In contrast the red curve #3 is a Bandpass design, having a small hole (port) in front of the speaker. This port is tuned to 4000 Hz, after which the response drops at higher frequencies. Again the input voltage was adjusted to give a max excursion of 0.28mm, giving a max SPL of ~83 dB at 0.1m. However there is a very large peak at 4000 Hz.

Choosing the InterPort option (Figs. 1 & 3) and adjusting the InterPort Q to 0.9 (Fig. 4), brings down the peak and gives a quite flat Bandpass response (green #4). The high damping (lower Q) is made by covering the (Inter-) port with a cloth or felt, which will pass air but add damping. Actually the front port can be damped in the same way. Max SPL is ~84dB (2-5 kHz).

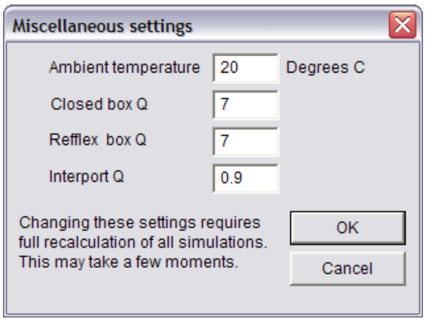


Figure 4 - Setting Port Q and damping

The calculated Voice Coil and magnet temperatures are shown in the upper right picture of Fig. 1. The Voice Coil is at 28.9 degrees C which is no problem.

However if the speaker was used in a car, then setting the ambient temperature to 55 degrees C or higher would simulate the maximum temperature in the sun. In this case the max temperature would be 83.9 Degrees C, which would demagnetize a standard grade Neodymium magnet. This way the designer can actually verify which magnet grade to use.

The ports can be changed by modifying the port diameters (Fig. 5), and the length will automatically be simulated according to the chosen tuning frequency. A flange (trumpet) can reduce port noise/whistling.

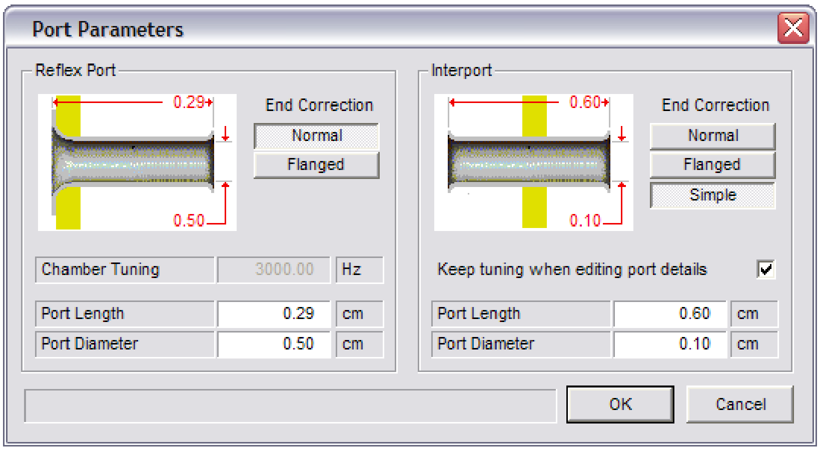


Figure 5 - Change of Port diameters and simulated lengths

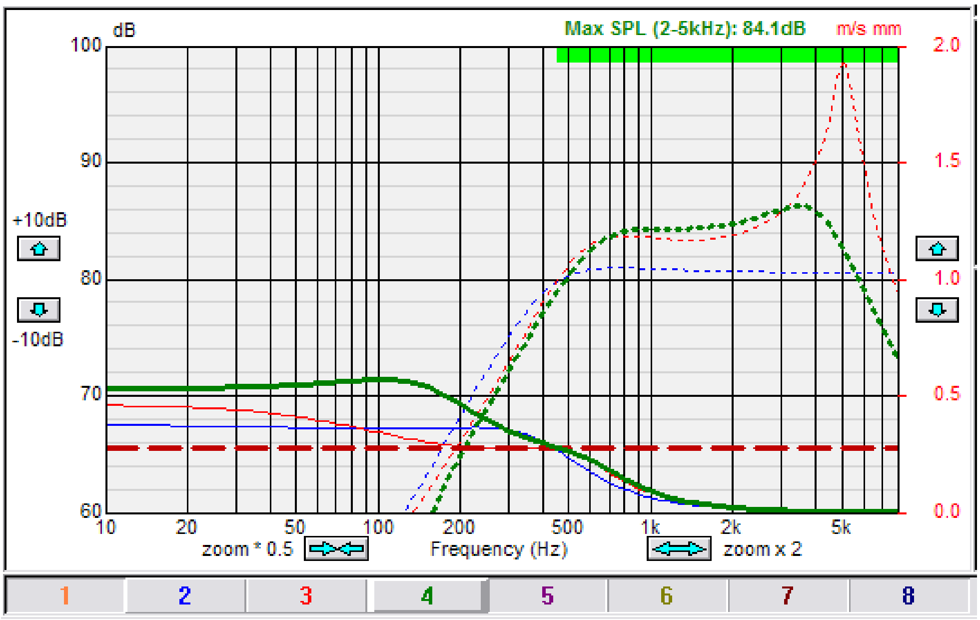


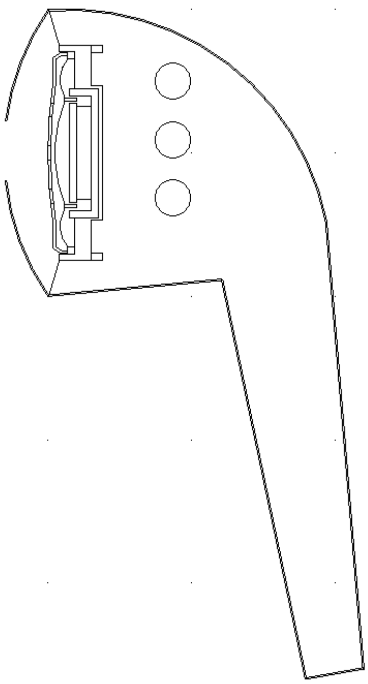
Figure 6 - Excursion of 15mm closed/Band pass/InterPort from Fig. 4

Fig. 6 shows the VC excursion of the 3 designs, where the input was set to produce 0.28mm (Xmlin) at the resonance frequency (Fs) in the box. Because the excursion is increased at low frequencies, the design with the higher box resonance (green #4) can produce a higher SPL in the pass band. However in order to prevent problems, it is advisable to insert a High Pass filter to limit the VC travel below Fs.

Headphone/Earphone with cavities and holes/channels

A more advanced example is a small earphone (Ear bud), which is sketched in the next figures 7 and 7A. This can be modeled using the “Other” option in the latest FINEBox (with Micro option). A full simulation model is extremely complicated.

Here is proposed a simplified model, using lumped elements while assuming an infinite baffle (no Coupler or Artificial Ear). This method is convenient for measuring and verifying the performance, as well as investigating and optimizing the different cavities and holes.



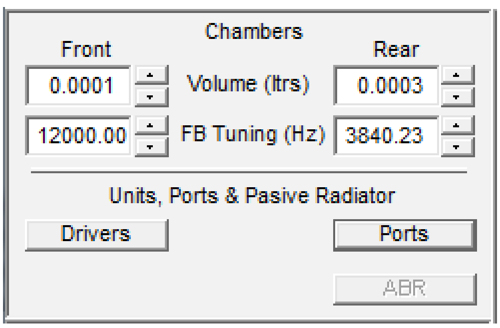


Figure 7A – Front and rear chambers of Earphone

Figure 7 - Typical Earphone (Ear bud)

The earphone above is an example of the typical small (on-ear) ear bud used with smart phones and Mp3 players. The driver is around 15mm in diameter and there is usually a very small cavity in front having one or more holes to the outside. The rear cavity is larger, but still quite small, causing a driver resonance in the order of 2000 Hz.

This is illustrated in Fig. 8 as the khaki green response, showing a sharp resonance around 2000 Hz when the small holes are closed.

The purple curve is the final simulated response including the small holes and the large tube (along the lead wire). The amplitude of the large resonance is considerably reduced and the tube acts as a bass reflex giving good response down to 200 Hz. This is the free field response, but the near-field response may extend below 20Hz, when the earphone is attached without leak to the human ear. The leak however, is quite difficult to avoid and will vary with the position etc.

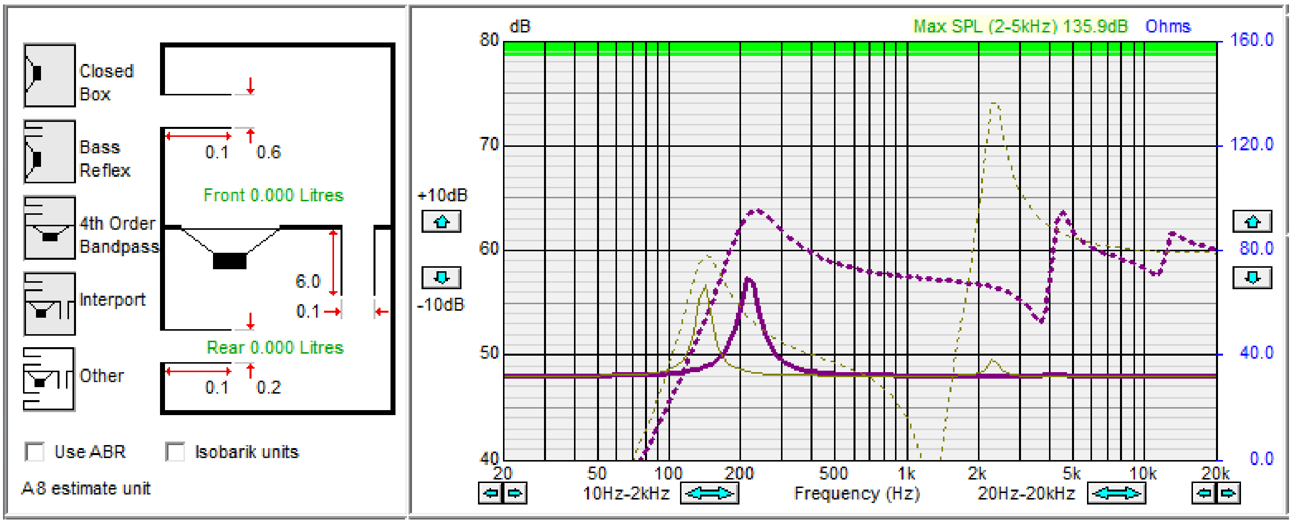


Figure 8 - FINEBox simulation of Earphone (Ear bud)

So far we have assumed the driver response to be linear without break-up. In the next chapter let us therefore analyze the break-up in more detail using FINECone.

Acoustical Finite Element Simulation with FINECone

The acoustic FINECone simulation can help the engineer to decide the cone thickness, cone profile and material for obtaining the best frequency response and low resonance.

Larger headphones which fully cover the ear (Circumaural) use larger drivers, normally around 38-40mm diameter. Fig. 9 shows some direct measurements of 30-40mm headphone speakers (capsules). The responses are far from flat due to break-up in the cone (diaphragm), which is especially visible in the waterfall. Let us therefore analyze a typical good one in FINECone.

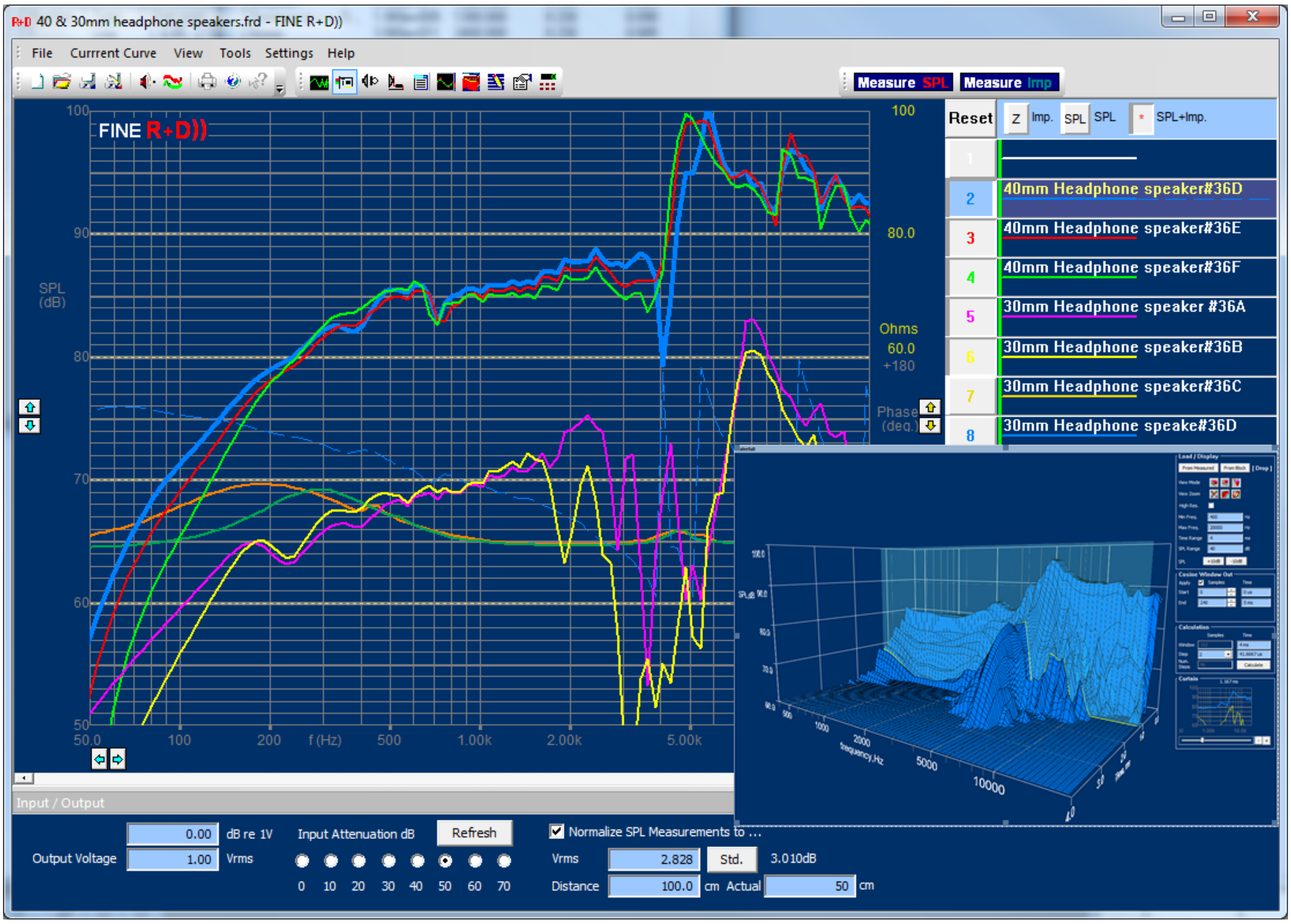


Figure 9 - Typical responses of good 30/40mm headphone speakers (capsules)

The geometry of the 38mm Headphone speaker was specified as a simple DXF file in the FINECone simulation. The materials for the diaphragm are inserted from the standard database, see Fig. 10.

New materials may be added to the Material Database. In case the material data are not known, a documented method can be applied to find these data using measured frequency responses. (See the FINECone Manual).

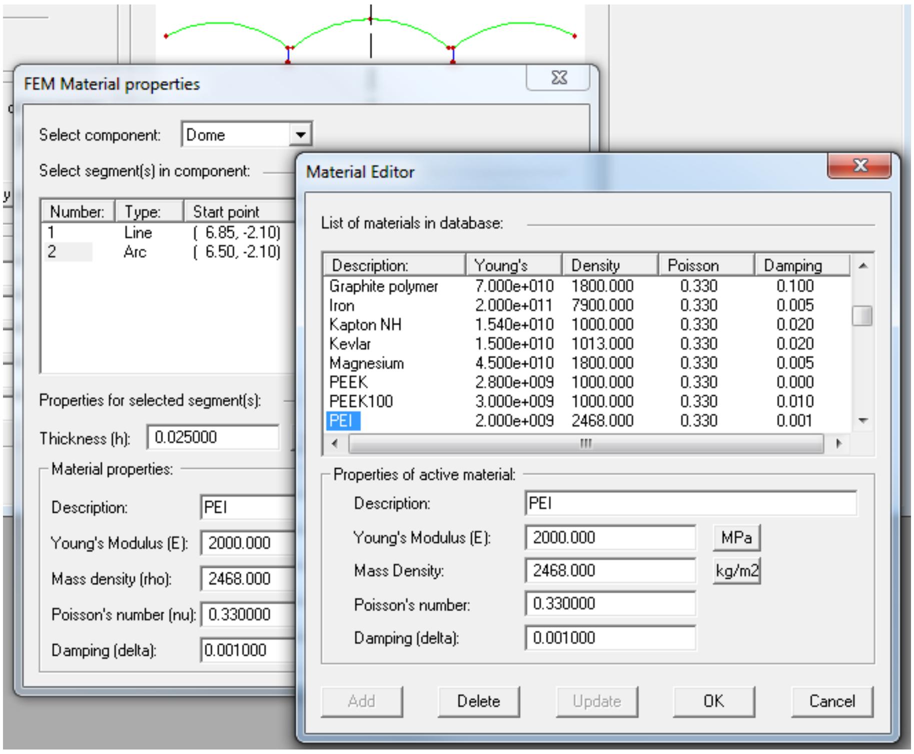


Figure 10 - FEM Material input from Database

Fig. 11 shows the 38mm headphone simulated in FINECone. The first break-up takes place at 3165 Hz, where there is considerable break-up in the middle of the large surround. Since the surround area is a large percentage of the total cone area, the break-up here will influence the response considerably. The calculated responses (0/30/60 deg. off-axis) including break-up is shown in the next Fig. 12.

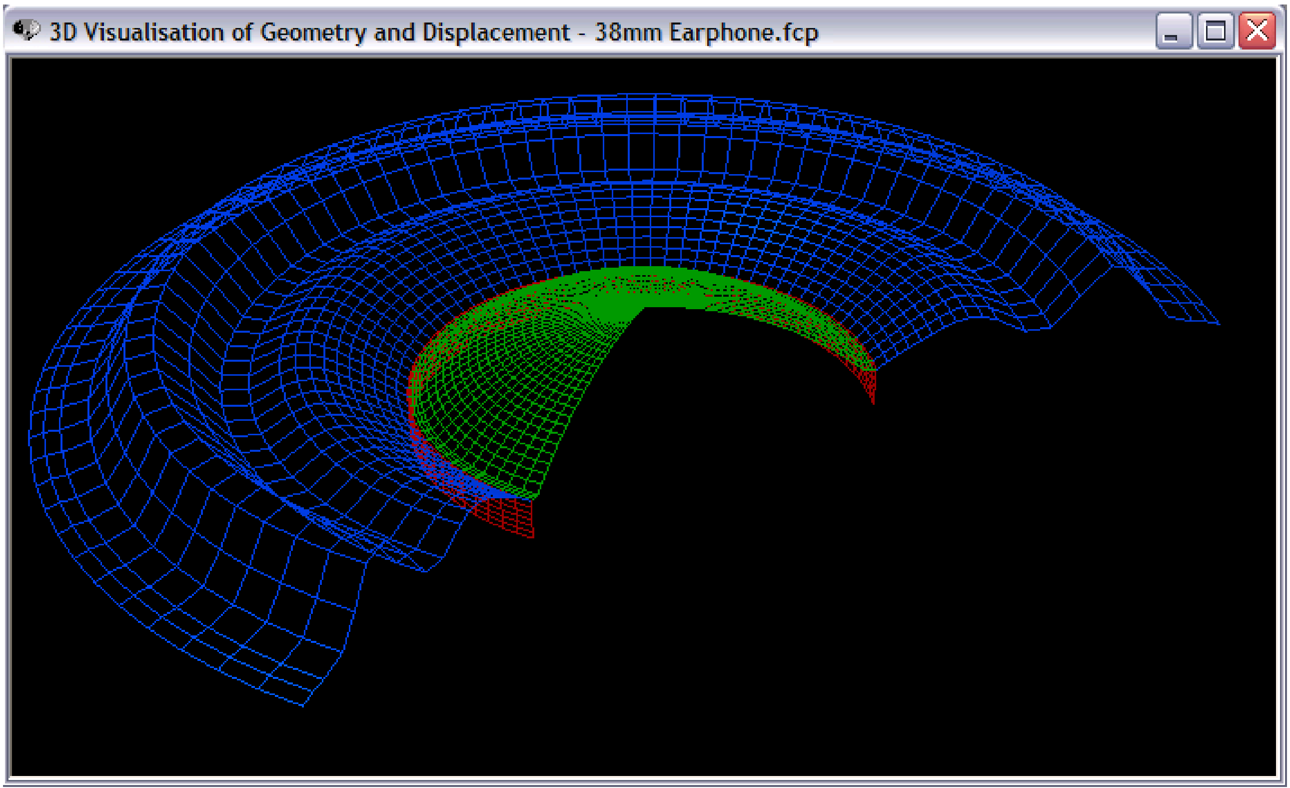


Figure 11 - 38mm Headphone speaker with break-up at 3165 Hz

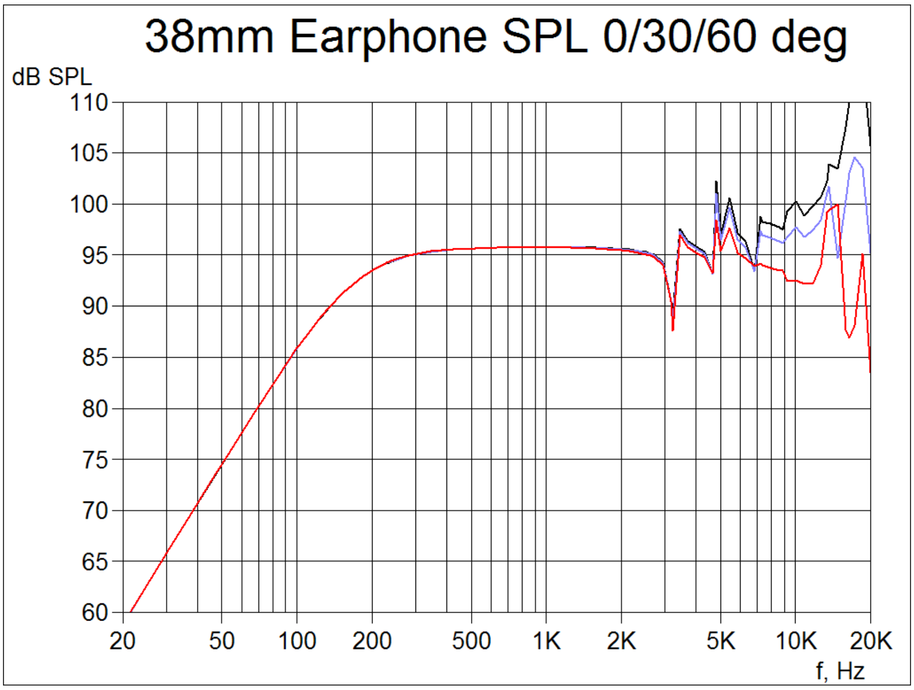


Figure 12 – Response with break-up of the 38mm headphone speaker from FEM

From 3165 Hz to 20k the response is dominated by break-up, which certainly is audible. The break-up is caused primarily by the shallow geometry. The 38mm headphone speaker may be recalculated with an optimized geometry and other materials.

Once a good response has been found using the best geometry and material, the next challenge will be to lower the resonance Fs. A pattern in the surround can help that to some extent, see Fig. 13. The pattern will effectively make the diaphragm thinner for obtaining a low Fs, but the high profile will prevent high-frequency break-up to some extent.

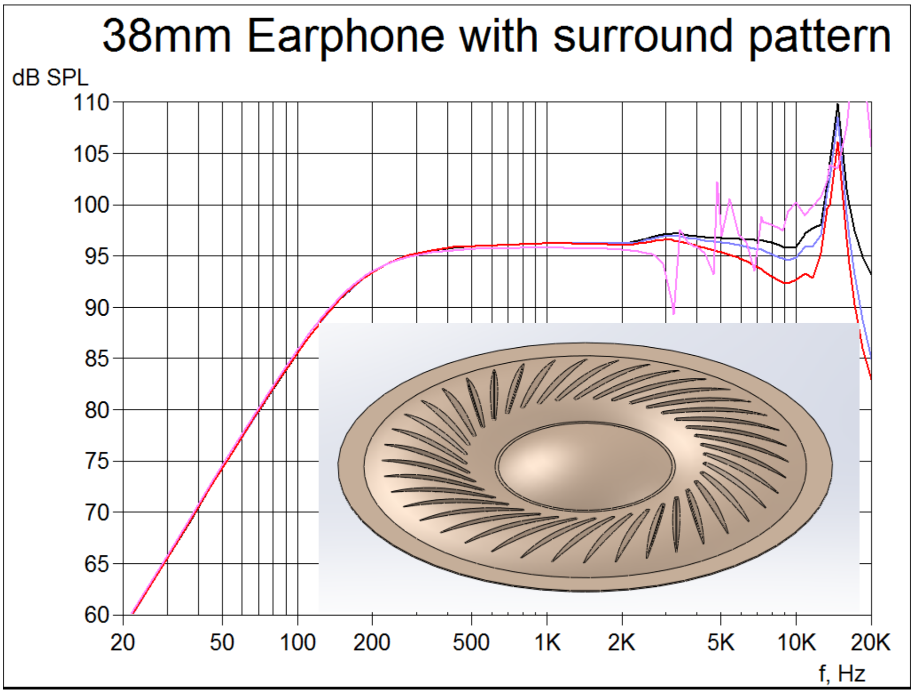


Figure 13 - 38mm headphone diaphragm with low Fs pattern, simulated in FEM

FINEMotor Simulation.

Finally let us analyze the 15mm micro motor system in FINEMotor. The magnet material is Neodymium N42. The DCR resistance is 7.0 ohms (Z nominal imp= 8 ohms). The winding width in FINEMotor was very close to the actual 1.05mm when a stretch of 5% was set. (The winding is normally stretched some % during winding).

An oval diaphragm should just use the active area (including half surround) as input.

Figure 14 - 15mm Neodymium motor system modelled in FINEMotor

Note that the magnet system has a very thin top plate, which is saturated, indicated in red. (Top plate Bt =2.39T. (Bt must be <=2.1T)

The Voice Coil is not placed symmetrically in the air gap, but offset 0.25mm up. The BL(x) curve shows how the force factor BL varies when moving up through the air gap. The ideal BL(x) curve is flat and symmetrical, but in this case it is NOT symmetrical. The usable range for getting low distortion is when BL is higher than 82% of the maximum value (green range).

Here we get Xmax (up) = 0.613mm, but only Xmax (down) = 0.141mm, which is quite bad. In other words the usable Xmax is only 0.14mm.

First we move the Voice coil by dragging with the left mouse button. This makes the BL(x) curve quite symmetrical. Next we need to increase the top plate thickness to avoid saturation. In the next simulation the Voice Coil is moved to center, and the top plate has been increased from 0.3 to 0.45mm, which increased the sensitivity about 1dB and Bt is now just at the limit (2.11T).

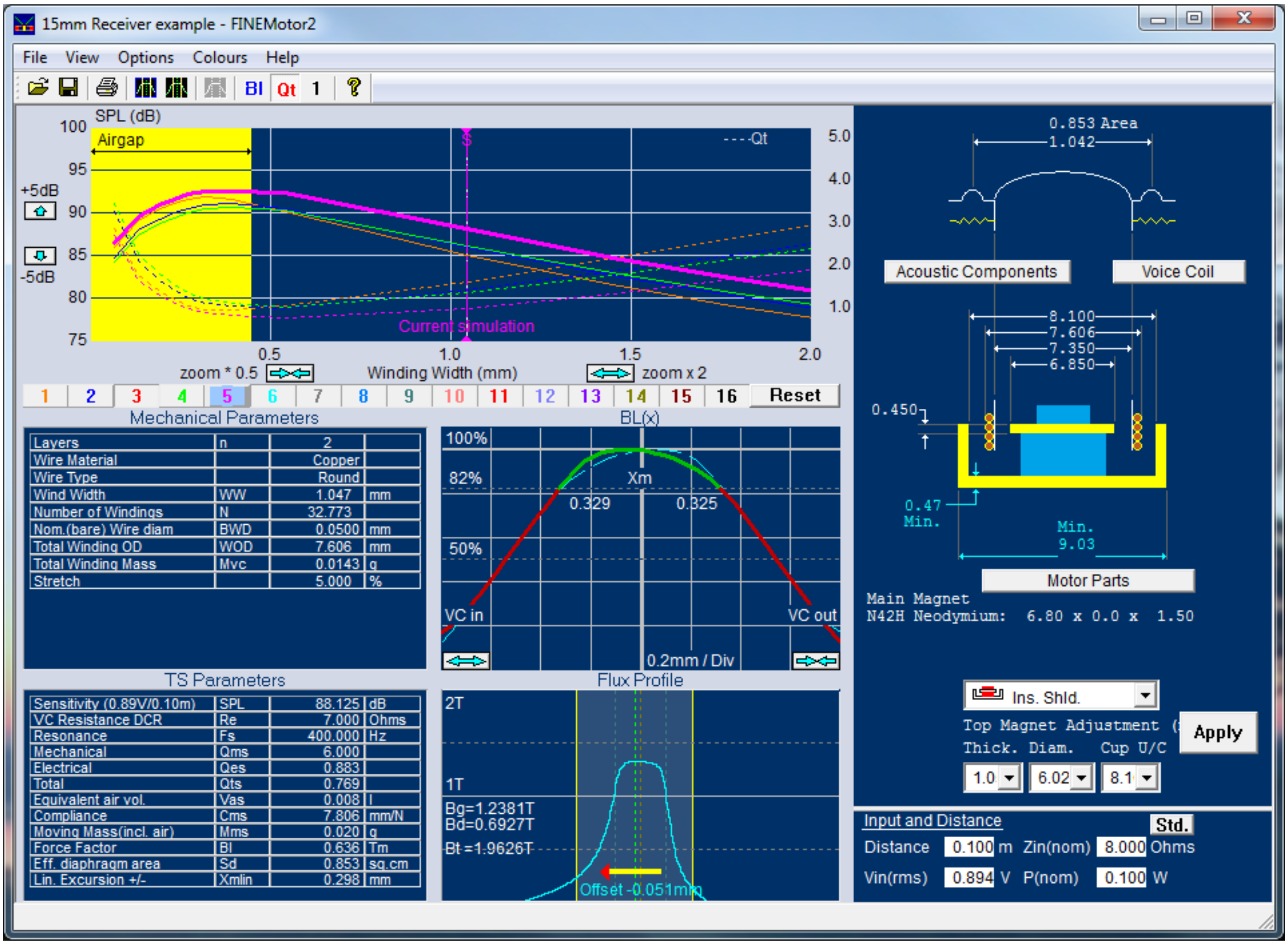


Figure 15 - Optimized 15mm neodymium motor system including top magnet

There is another way to obtain more SPL from the micro speaker: By placing a second neodymium magnet (magnetized opposite) on top of the top plate, some of the leakage flux is forced back into the air gap thereby giving higher sensitivity.

That is shown in Fig. 15. Note you can adjust both the thickness and diameter of the top magnet, while observing the BL(x) curve change and all TS parameters updating automatically.

Finally we may improve the 15mm micro receiver by using Ferrofluid in the air gap. There are 3 significant advantages by doing so.

The power handling is increased considerably due to the cooling with the Ferrofluid in the air gap. Actually the Ferrofluid can be selected to add much damping at resonance (Fs), which prevents distortion and increases power handling.

In addition the air gap can be made smaller, which will increase SPL and improve cooling.

The next picture fig. 16 shows the exact volume of Ferrofluid to be dispensed in the air gap, the saturation strength, and viscosity.

Mechanical Parameters

Layers	n	2	
Wire Material		Copper	
Wire Type		Round	
Wind Width	WW	1.05	mm
Number of Windings	N	32.77	
Nom.(bare) Wire diam	BWD	0.050	mm
Total Winding OD	WOD	7.61	mm
Total Winding Mass	Mvc	0.014	g
Stretch		5.00	%
Ferrofluid Volume	FF vol	4.19	uL
Ferrofluid Saturation	FF sat	200 - 150	Gauss
Ferrofluid Viscocity		200.00	Cps

TS Parameters

Sensitivity (0.89V/0.10m)	SPL	86.56	dB
VC Resistance DCR	Re	7.00	Ohms
Resonance	Fs	400.00	Hz
Mechanical	Qms	1.16	
Electrical	Qes	1.27	
Total	Qts	0.60	
Equivalent air vol.	Vas	0.01	l
Compliance	Cms	7.81	mm/N
Moving Mass(incl. air)	Mms	0.02	g
Force Factor	Bl	0.53	Tm
Eff. diaphragm area	Sd	0.85	sq.cm
Lin. Excursion +/-	Xmlin	0.32	mm

Figure 16 - Calculated TS parameters including Ferrofluid

The Ferrofluid is specified (in red). First is the exact volume as per the formula given by Ferrotec, then the necessary magnetic saturation strength and finally the chosen viscosity.

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