A small chamber for the calibration of microphones below 500 Hz

An article by Alex Khenkin from Earthworks [1], a manufacturer of high quality microphones, makes one curious to try out a method of calibrating omni directional microphones below 500 Hz.

In the named article - which is worth reading for everybody who wants to know something about the calibration of microphones - the following paragraph can be found:

"Measuring very low frequencies by the substitution method is problematical because such tests require a very large anechoic space. To measure in frequency range from zero to 500 Hz, we use a small, piston driven pressure chamber. This method is actually a primary frequency response calibration, since the pressure in a given size chamber at a given temperature depends only on the volume displaced by the driving piston. The high frequency limitation is defined by the chamber size, which should be less than 1/6 wavelength in any direction. Of course, this only works for pressure microphones (omnis)."

In ranges above 500 Hz Earthworks uses the substitution method in which the test object is measured on an infinitive baffle against a reference microphone. The lower the test frequency, the more problematic it is to find an appropriate sized and anechoic room and to keep the measurement clear of external effects. To avoid this, Earthworks uses a small pressure chamber for calibration in the lower frequency range.

The pressure chamber is also interesting for DIY-er. Under the premise that the chamber was once calibrated with a reference microphone, it is no problem, due to its small dimensions, to set the chamber up to calibrate any microphone in frequency response and level.

Functionality and construction of the measurement chamber

If the measurement chamber's longest dimension is shorter then 1/6 to 1/8 wavelength of the upper cut-off frequency, the chamber with a volume V behaves as an acoustic capacity

$$C_K = V / (\rho_0 c^2) \qquad (1)$$

with $\rho_0 = 1{,}18$ kg/m³ and $c = 344$ m/s. If the driver's membrane with area S and velocity v excites a box volume with the volume velocity $U = v\,S$ whole volume is approximately at equal acoustic pressure of

$$p_k = v\,S / \mathrm{j}\,\omega\,C_K\,. \qquad (2)$$

Membrane velocity and membrane displacement are in the relationship:

$$v = j\,\omega\,x \qquad (3)$$

By applying Eq. (3) in Eq. (2) we get that sound pressure in the box is proportional to the membrane displacement.

$$p_k = x\,(\,S / C_K\,) \qquad (4)$$

This property is of greatest importance as we will show later that in a closed box the membrane displacement as well as the pressure inside the box is constant at low frequencies.

Dimensions of a measurement chamber are easily calculated from the requirement that longest dimension must be 1/6 to 1/8 wavelength of the maximum frequency. At 500 Hz it is

$$\lambda = c / f = 344 / 500 = 0{,}67 \text{ m} \Rightarrow 1/6\lambda \text{ to } 1/8\lambda = 11{,}5 \text{ cm to } 8{,}4 \text{ cm}$$

The dimensions of the chamber are quite manageable.

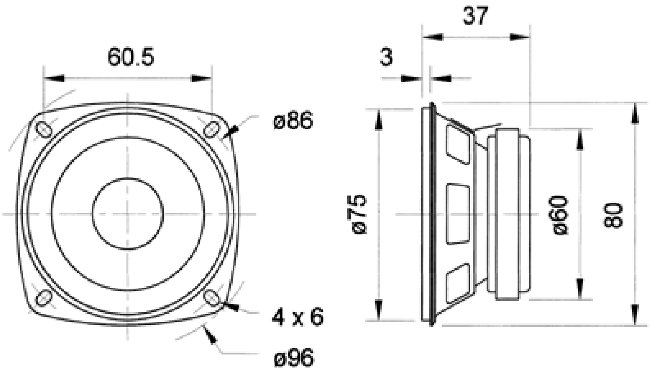


Figure 1 Visaton fullrange driver FRS 8

At first, a construction of two MDF plates, a piece of waste pipe with the length of 75 mm, and a small fullrange driver FRS8 by Visaton was used. The main dimensions of the measurement chamber are shown in Figure 2, the remaining dimensions are resulting from the used parts and should be determined when rebuilding the construction.

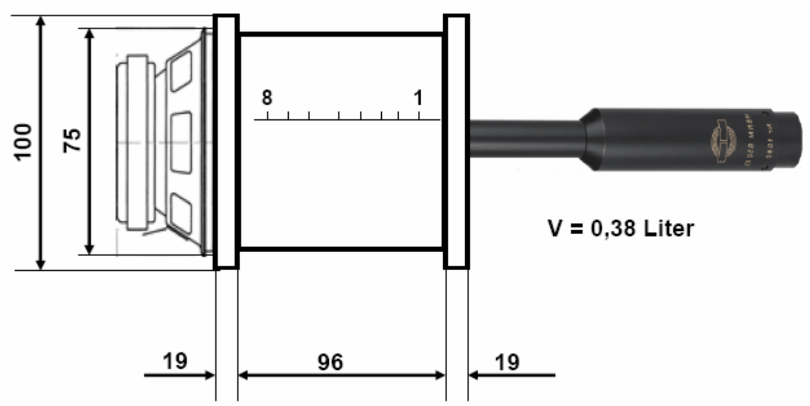


Figure 2: Construction of the measurement chamber

Quantity	Description
2	19 mm MDF, 10 x 10 cm
1	waste pipe, diameter 75 mm, length 110 mm
4	threaded bars M4 x 150 mm length
8	nuts M4
1	rod, beech, diameter 25 mm

Table 1 Measurement chamber part list

When plunging the pipe 7 mm into the MDF plates on each side, we get an effective tube length of 93 mm resulting with volume of 0,38 liter. More details concerning the construction are displayed in Figure 3. With given information and pictures the box construction procedure should be trouble-free.

Figure 3.1 Side view of the completed chamber

Figure 3.2 Rear view of the completed chamber with driver

Figure 3.3 Front view of the completed chamber with DUT

Figure 3.4 Front (interior view) with nut for grouting the waste pipe

Figure 3.5 Front (microphone) side with hole for 25 mm rod adapter for microphones

Figure 3.6 Rear panel (driver side), exterior view with nut inserting the driver

Properties of the pressure chamber

The appliance of the pressure chamber is to be taken from the figures 3.1 to 3.6. The tested microphone must be inserted in the chamber with the tightly sealed adapter. The insertion of the microphone in the chamber has the advantages that the measurement becomes quite independent from the surrounding and additional interferences are avoided. A backward muffling of the speaker would increase this effect.

In order to prepare for the actual measurement some preliminary tests and analysis are necessary to explain the measurement condition and sensitivity to variation of measurement parameters (microphone placement and sealing).

At first a Matlab simulation was carried out using the TS parameters of the FRS8 and the known chamber dimensions. Figure 4 shows the characteristics of the sound pressure level (SPL), the membrane displacement, the phase, and the impedance.

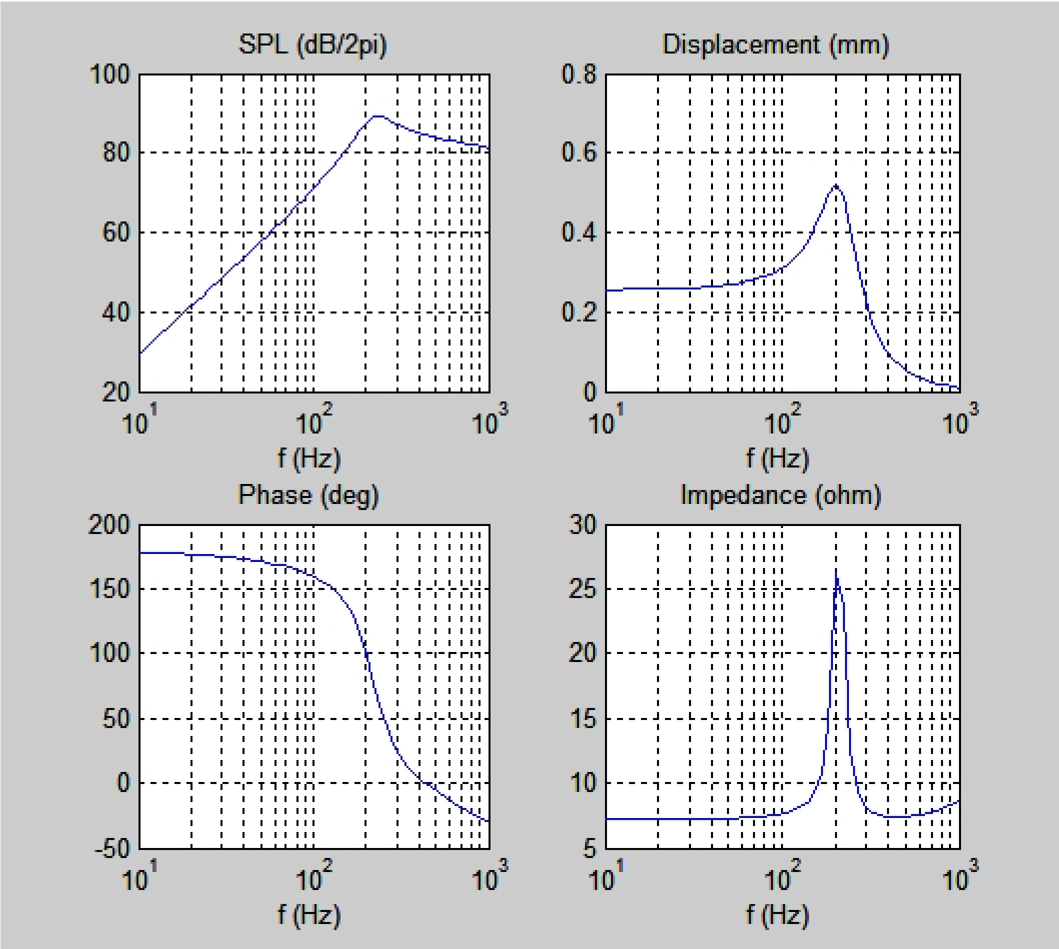


Figure 4 Matlab simulation of the FRS 8 response in 0.38 liter volume

Figure 5 shows the SPL of the FRS 8 inside the pressure chamber. SPL and displacement shows very similar characteristics, as predicted by Eq. (4).

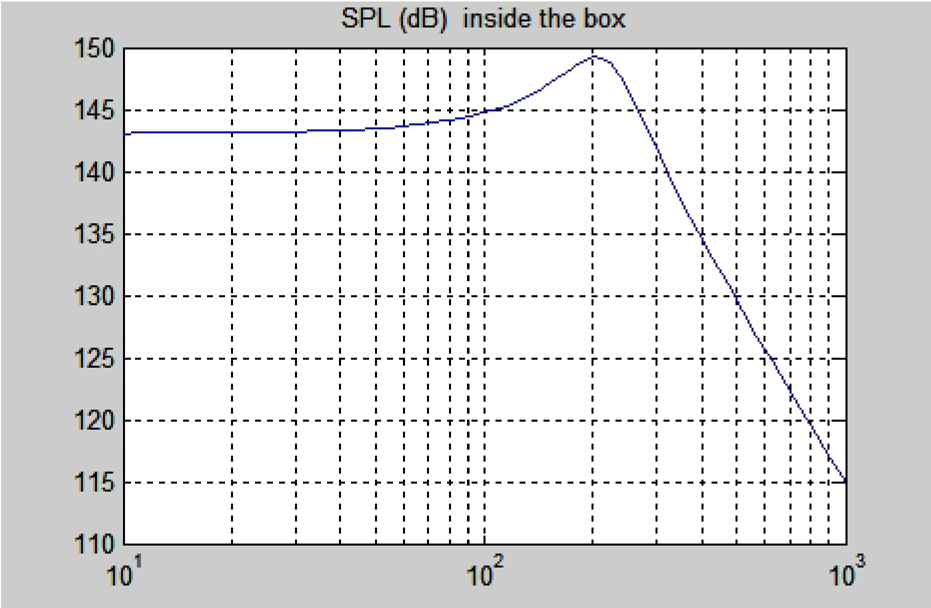


Figure 5 Characteristics of acoustic pressure inside the measurement chamber for 2.83V excitation (Matlab simulation).

The acoustic pressure in the chamber, for a 2.83 volt driver excitation, is remarkable high. Below the resonant frequency it amounts to about 145 decibel, thus being far above the margin for a maximum acoustic pressure of popular electret microphones.

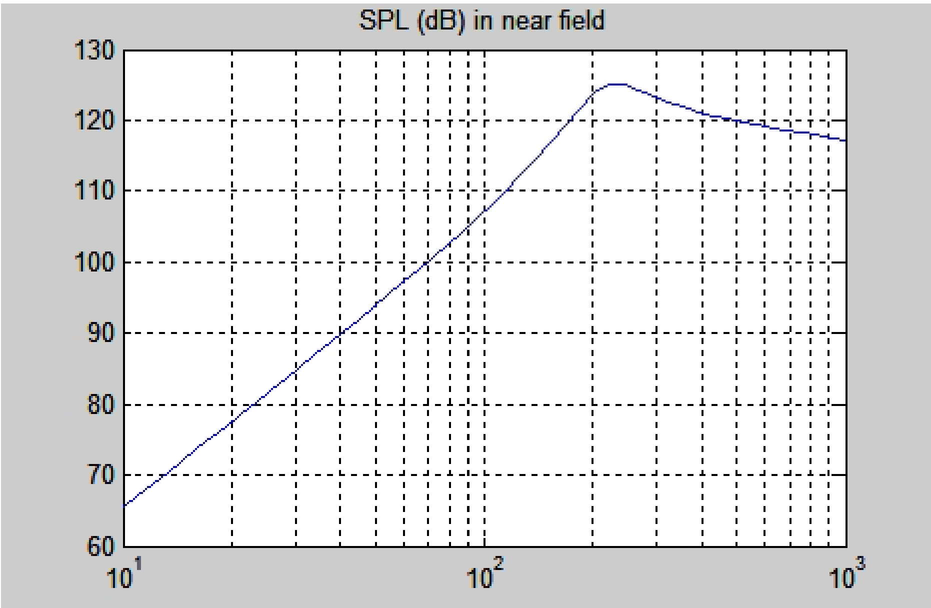


Figure 6 Characteristics of acoustic pressure in the near field. (Matlab simulation)

The acoustic pressure characteristics were also simulated for the outer near field in order to compare the measurements later (Fig. 6).

As shown in the Figure 5 we have to expect high acoustic pressure inside the chamber. To preserve the tested microphones from damage the excitation driver voltage has to be properly adjusted.

Figure 7 shows the results of the chamber SPL/ input voltage dependence at 100 Hz and 1000 Hz.

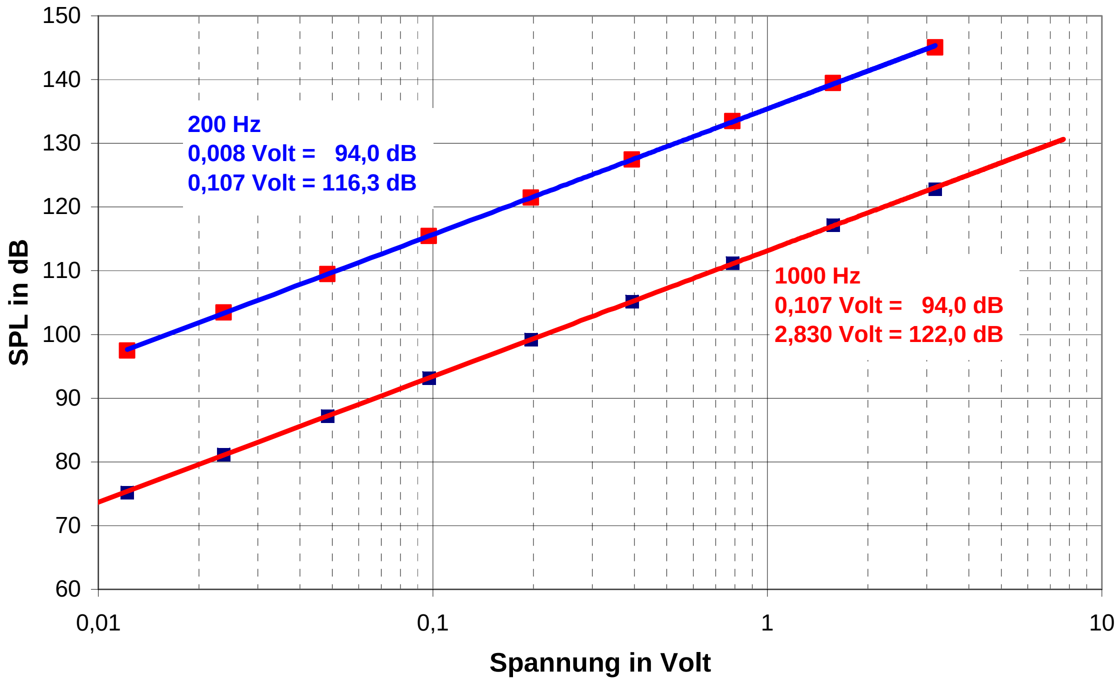


Figure 7 Sensitivity of the chamber pressure level in relation to the input voltage.

At 1000 Hz (the usual test frequency for calibrators) the chamber needs an input voltage of 0.107 V for an acoustic pressure of 94 dB.

In the frequency range below 200 Hz input voltages above 0.1 V should be avoided as severe distortions as well as damages of the microphone can occur (see annex 2). In this frequency range applicable input voltage for the calibration is about 0.01 volt RMS.

The measured data shown above apply only for the tested arrangement. With the exact abidance of the dimensions and the volume of the chamber as well as the use of the same driver it should be possible to reproduce the results with only minor differences.

In the second step the near field frequency response of the FRS8 was determined. Due to the assembly, the sound pressure could only be measured just behind the magnet (see figure 8). In comparison to the simulation it lacked about 15 dB acoustic pressures which could be a result of a different measurement setup. A control measurement with a FRS 8 in a open baffle confirmed the assumption. The difference of the pressure between front and back side in the near field is about 13.9 dB at 200 Hz.

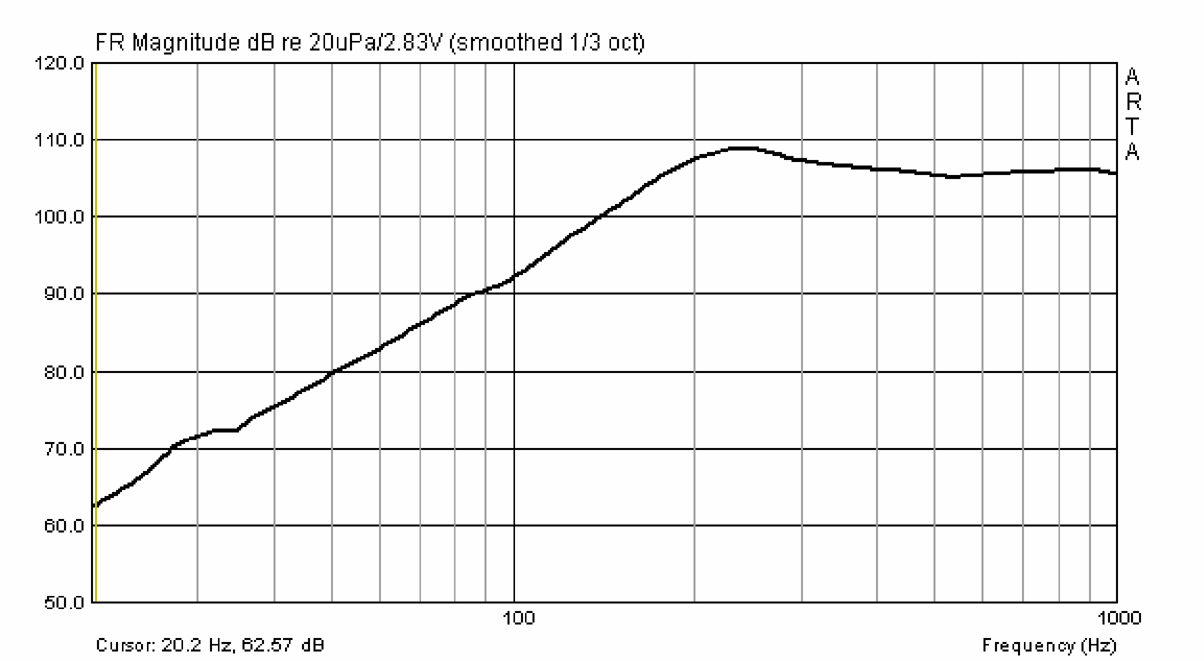


Figure 8 Characteristic of the acoustic pressure in the near field (microphone placed just near the center of the magnet)

Next, it was tested how much influence the position of the microphone has in the chamber on the results. The response was measured at 8 different microphone positions in a frequency range from 5 Hz to 1000 Hz. Position 1 is located 1 cm from the MDF-plate. Other positions are 1cm apart. Results are shown in Fig. 9 (compare with simulation on Fig. 5).

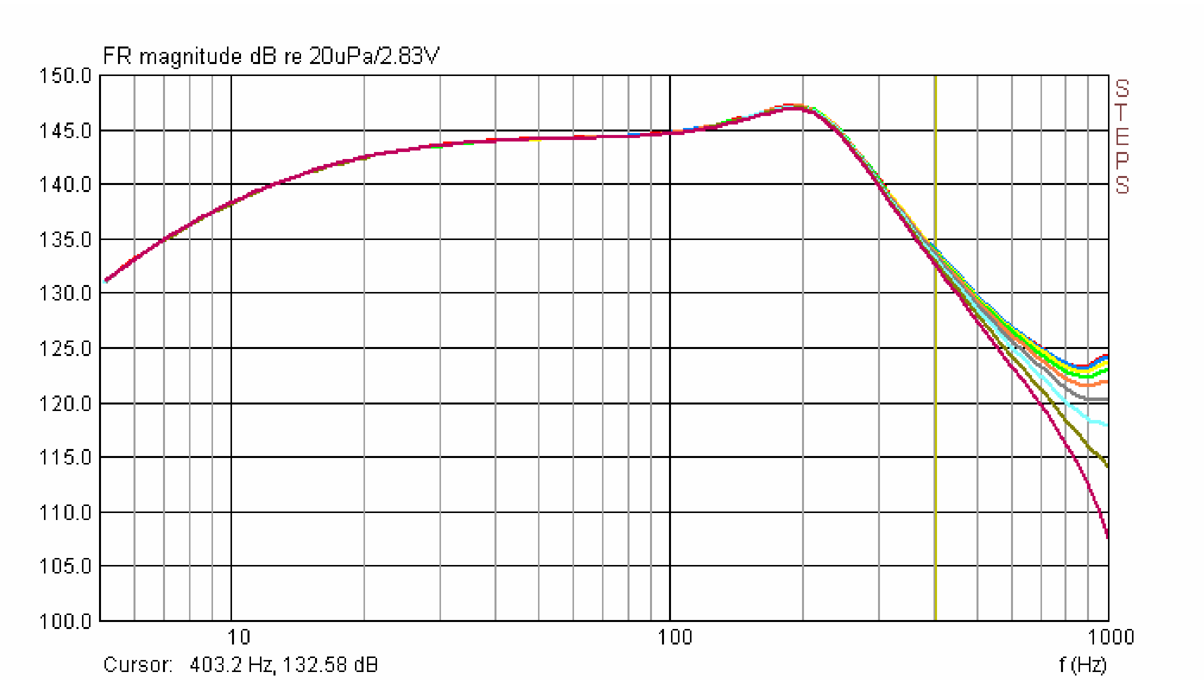


Figure 9 Frequency deviation of SPL in relation to the position of the microphone (WM 60).

Firstly, it stands out that the measurement above 20 Hz matches quite well with the simulation. The absolute pressure level as well as the characteristics of the frequency response is estimated well by the simulation.

Secondly, it can be seen that the influence of the position of the microphone becomes significant above 400 Hz. The analysis of the two most differing measurement points can be seen in table 2.

Position	100 Hz	200 Hz	300 Hz	400 Hz	500 Hz
Pos 1 cm	144,73	147,12	140,25	134,00	129,62
Pos 8 cm	144,65	146,82	139,48	132,58	127,21
SPL difference (dB)	0,08	0,30	0,77	1,42	2,41

Table 2 Dependence of the measurement position

If the position of the microphone is held constant (+ / - 1 cm) it can be assumed that the difference will always be less then 1 dB at 500 Hz.

A third parameter, the influence of the seal of the chamber was investigated. Figure 10 shows the results. The blue curve stands for a chamber accurately sealed with lute, the red curve stands for a measurement with an adapter for the microphone but with less sealing (small gap), and the black curve stands for a measurement without adapter and no sealing (bigger gap).

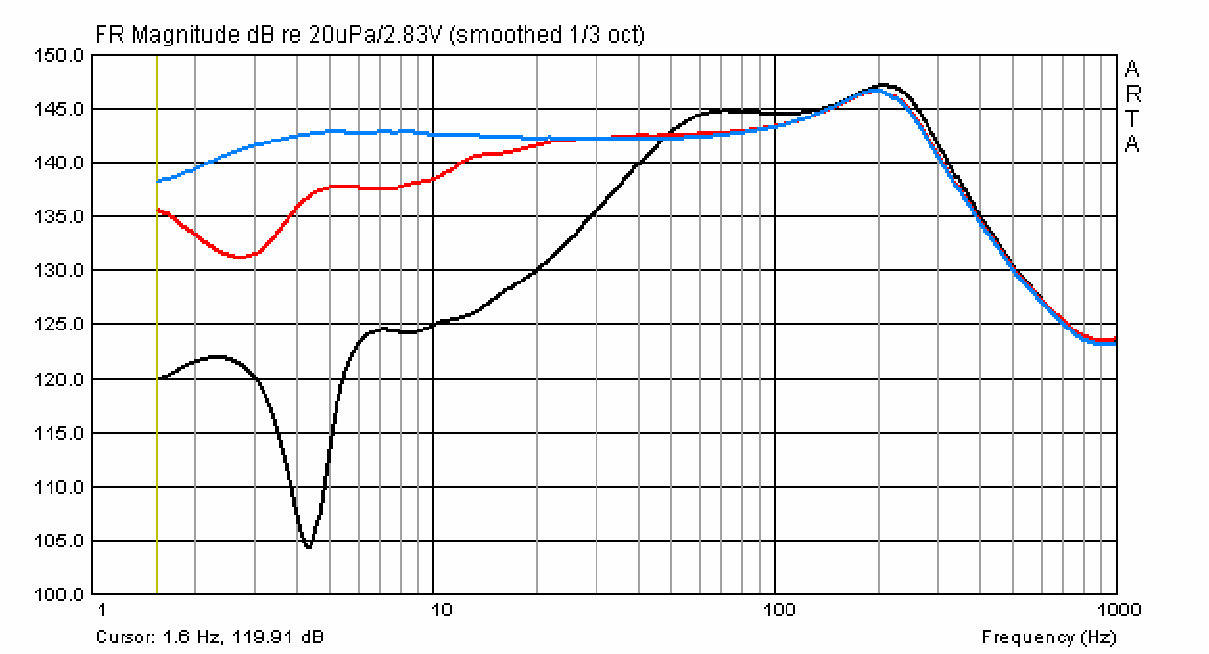
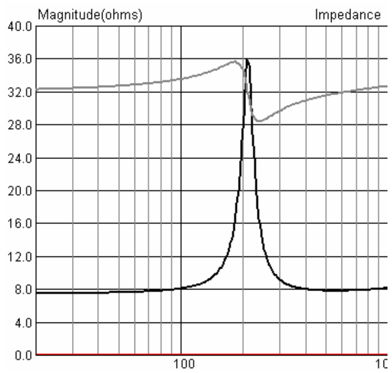


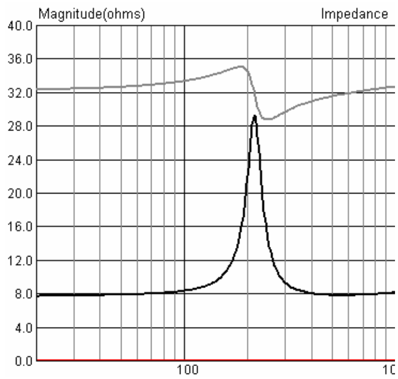
Figure 10 Dependency on FR of chamber sealing with microphone MK 221.

What is obvious immediately is that the chamber must be well sealed or the measurement will be erroneous.

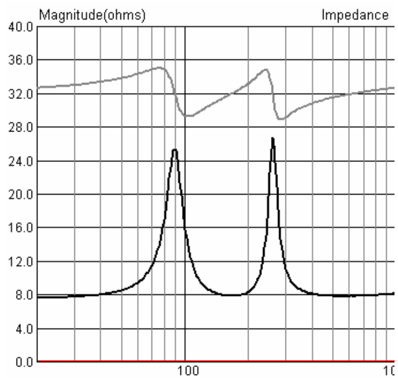
The seal should be no problem with lute and some experience. The leakage can be detected as change of the frequency response or the loudspeaker impedance curve. Figure 11a shows the impedance curve for a fully sealed chamber, Figure 11b shows the impedance curve for the chamber with small opening around microphone adapter, and figure 11c shows impedance curve for the chamber with open 13 mm adapter.



a) fully closed box



b) with small gap



c) with larger gap

Figure 11 Effect of the gap size on the loudspeaker impedance curve

Calibration Measurement

For the calibration measurements the microphone MK 221 by Microtech Gefell was used as reference.

Technische Daten/Specifications MK 221	21.31 / 92.58 PTB-Zulassung-Nr. zur amtlichen Eichung CE
Wandlertyp Transducer type	Kapazitiver Druckempfänger Capacitive pressure transducer
*Frequenzbereich des Freifeldübertragungsmaßes *Frequency range free-field response	3,5 Hz ... 20 kHz (± 2 dB)
*Feld-Leerlauf-Übertragungsfaktor/Sensitivity	50 mV/Pa
Grenzschalldruckpegel für 3 % Klirrfaktor bei 1 kHz Max. SPL for THD ≤ 3 % at 1 kHz	146 dB

Figure 12 Extract of the specifications of the reference microphone

The frequency range of the microphone is denoted as 3.5 Hz to 20 Hz +/- 2 dB, the maximal acoustic pressure of 146 dB gives some reserve compared to usual DIY electret microphones.

Figure 13 shows results of measurements of the frequency response with STEPS and the microphone MK 221 inside the chamber. The measurement is almost identical with the simulation in this case.

Theoretically, for good sealed enclosure, a calibration of a microphone frequency response can be done without the comparison with a reference microphone.

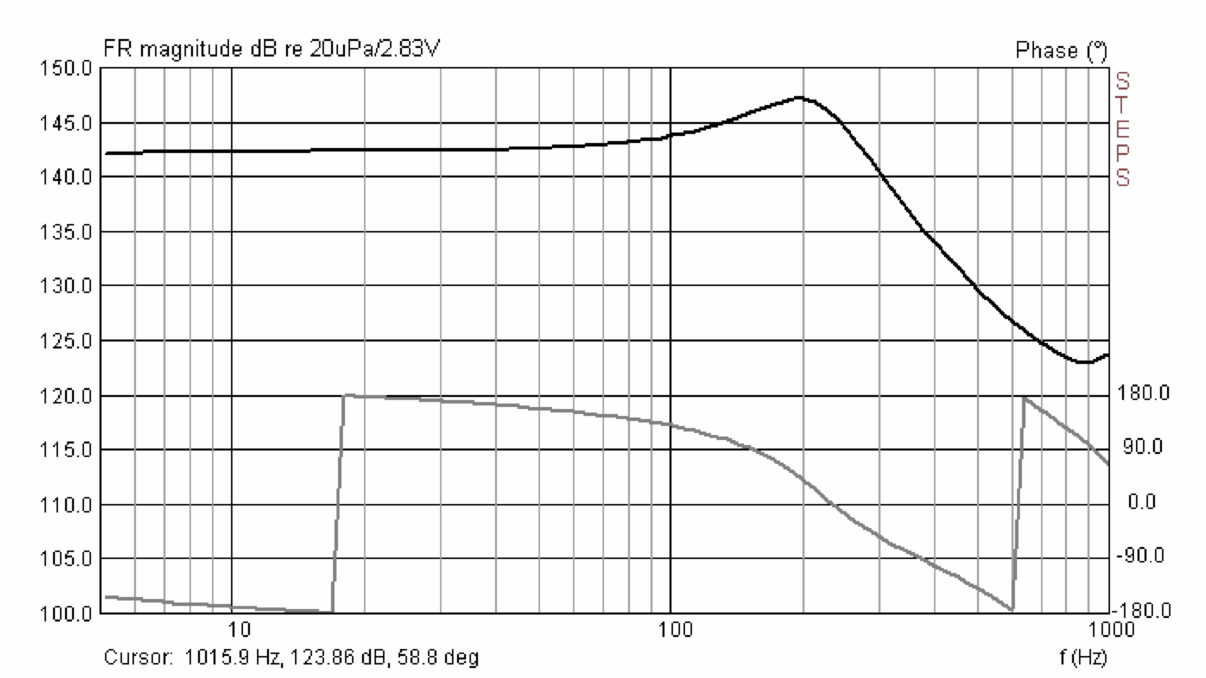


Figure 13 Reference frequency response in the measurement chamber

For the calibration following microphones were available:

- Measurement microphone MB 550
- 2 Sennheiser KE4-211 (different sized capsules)
- MCE 2000, Monacor
- WM 60, Panasonic

The following example shows, how the calibration curve for the microphone which is being calibrated is determined on the basis of the reference curve.

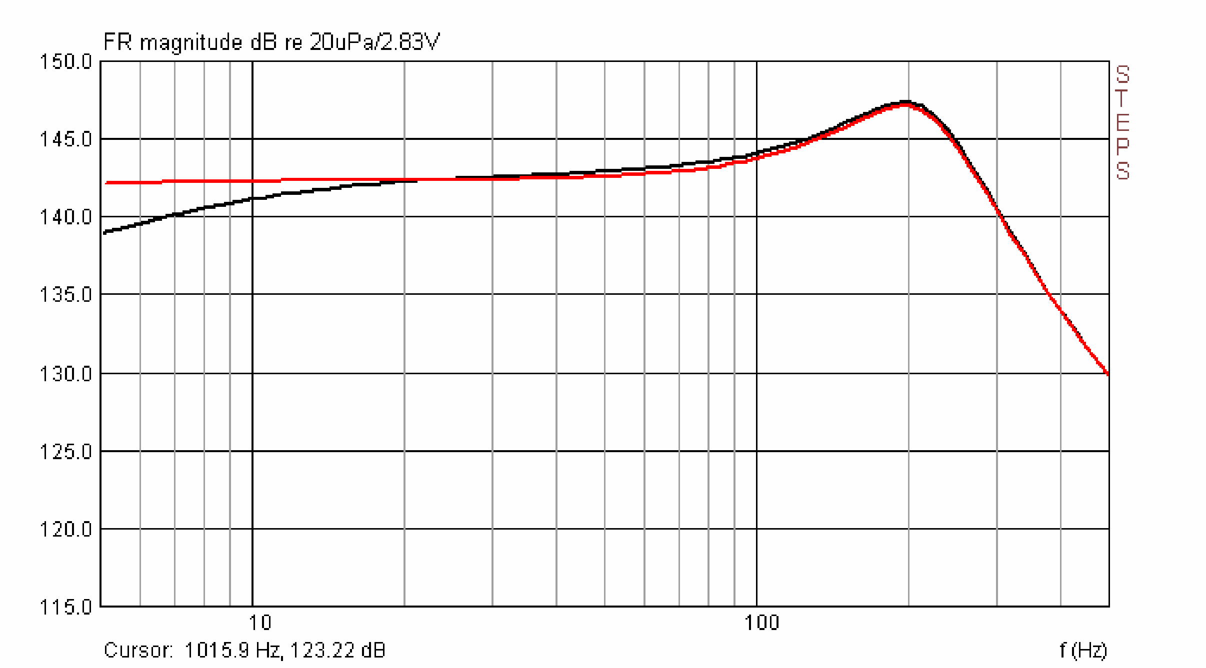


Figure 14 Response of MB 550 microphone (black) and reference frequency response (red), after scaling of the pressure level

Normally, it can be assumed that microphones have different sensibilities. Therefore a scaling of the pressure level is necessary. The easiest way to do this is to define a reference frequency with the cursor and read out the magnitudes at the bottom of the graph. The difference between the two curves is to adjust with **‚Scale'** (figure 14).

When measured with ARTA, the difference can be created with **Edit** -> **Subtract Overlay'**.

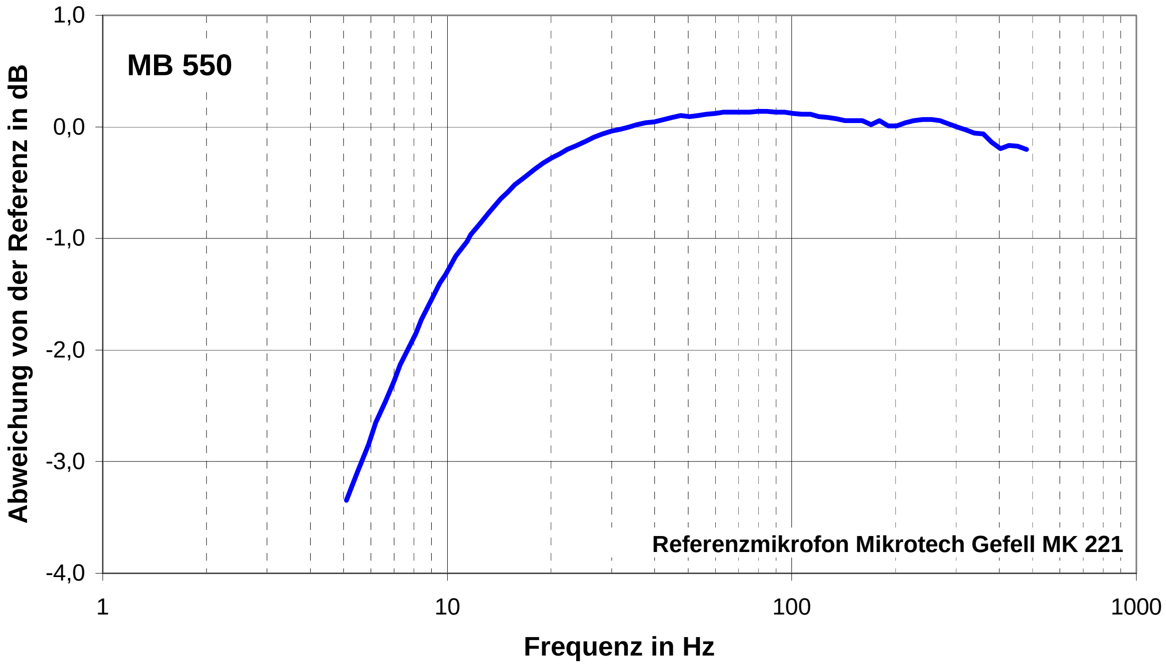


Figure 15 MB 550 - difference from the reference microphone frequency response

When measured with STEPS (better repeat accuracy) a minor detour to Excel or a appropriate simulation program (e.g. CALSOD) is necessary.

Figure 14 shows the results for the microphone MB 550 determined with STEPS. The results of the remaining microphones are shown in figure 16.

It becomes obvious that noticeable deviations between DIY-microphones below 50 Hz are common. Even comparatively high quality microphone capsules (KE4-211) do not guarantee that deviations from the specification or variation inside a lot of capsules are negligible.

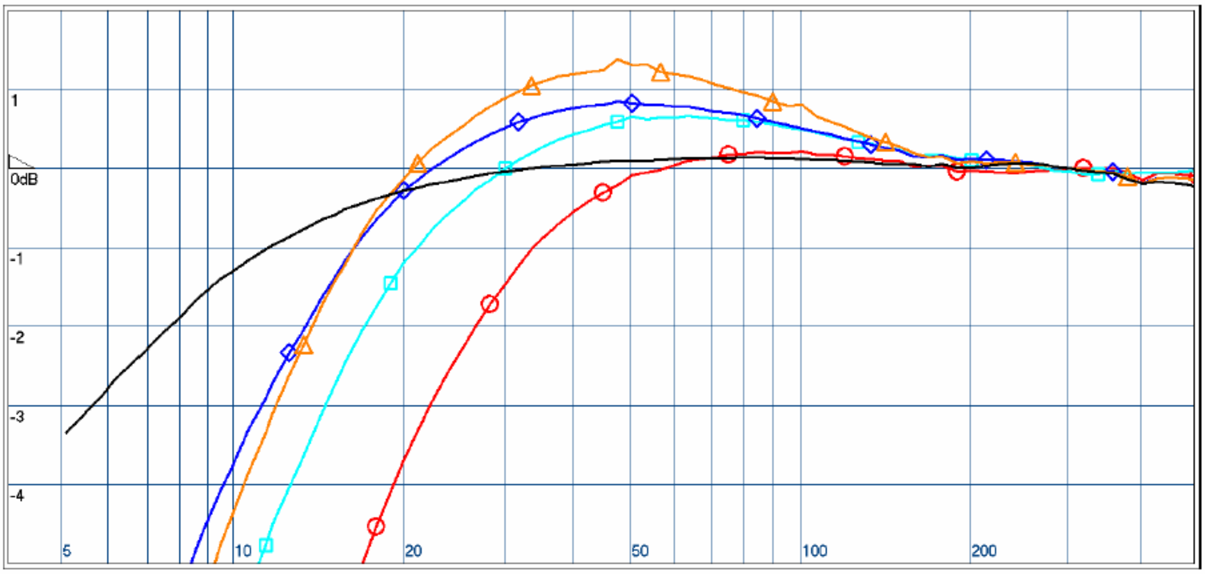


Figure 16 Calibrated frequency response of the tested microphones: black (MB 550), red (KE4-221, Nr1L), cyan (KE4-211, Nr2K), blue (MCE 2000), orange (Panasonic WM 60).

Conclusion

With the described pressure chamber it is easy to calibrate microphones up to 500 Hz. It is optimal to calibrate the measurement setup with a reference microphone and save data as STEPS or ARTA calibration file. But even without a reference microphone, a calibration should be possible on the basis of a simulation, as the example above shows.

The cost for the building of the chamber is very low, so there is no serious reason not to try this small experiment.

HWE / IM
01.08.2006

Literature

[1] Alex Khenkin, How Earthworks Measures Microphones, published at www.earthworks.com

Appendix 1 - Matlab script for the loudspeaker closed box response

```
clear
echo off
j=sqrt(-1);
f = logspace(log10(10),3,50);
n = max(size(f));
w = 2*pi*f;
c=344; r0=1.18;
%------------------ start user Input
%input voltage
e=2.83;

%box volume
Vol = 0.39e-3;

%distance 1m
r=1;

%driver parameters (i.e. FRS 8)
Re = 7.2;
Le=  0.85e-3;
fs=120;
Bl = 3.2;
Sm = 31e-4;
Vas = 0.91e-3;
Qt = 1.04;
Qe = 1.32;
Qm = 4.85;
%----------------------- end user input

Cm = Vas/(r0*c^2*Sm^2);
Mm=1/((2*pi*fs)^2*Cm);
Rm = 1/((2*pi*fs)*Qm*Cm);
a=sqrt(Sm/pi);
ws=2*pi*fs;

pout = ones(1,n);
pin = ones(1,n);
pnf = ones(1,n);
xuk=ones(1,n);
zul=ones(1,n);

%radiation impedance constants
ra1 = 0.1404*r0*c/a^2;
ra2 = r0*c/(pi*a^2);
ma1 = 8*r0/(3*pi^2*a);
ca1 = 5.94*a^3/(r0*c^2);

% box constants
Cb=Vol/(r0*c^2);   %box compliance
Mao=0.85*a*r0/Sm;  %membrane air mass loading

for k=1:n
        ww = w(k);  jw = j*ww;
        % radiation impedance
        z1 = jw*ma1;          z2 =1/(jw*ca1);
        z3=z2*ra1/(ra1+z2); z3= z3+ra2;
        Zar=1/(1/z1+1/z3);

        %box analogous circuit
        Ze= Re + jw*Le;
        Zm= Rm + jw*Mm +1/(jw*Cm);
        A11 = Ze*Sm/Bl;
```

```
        A12 = Ze*Zm/(Sm*Bl) + Bl/Sm;
        A21 = Sm/Bl;
        A22 = Zm/(Sm*Bl);
        Zak =Zar + jw*Mao + 1/(jw*Cb);
        zul(k)= (A11*Zak+A12)/(A21*Zak+A22);
            %volume velocity
        U1 = e/(A11*Zak+A12);
        %displacement
        xuk(k) = (U1/Sm)/jw;
        %presure at distance r (infinite baffle mounted)
        pout(k) = jw*r0*U1/(2*pi*r);
            %pressure inside the box
        pin(k) = U1/(jw*Cb);
        %near field pressure
        kk = ww*a/2/c;
        pnf(k)= jw*r0*(U1/(a*pi))*sin(kk)/kk;

end

%level in far filed (db/1m)
pdb= 20*log10(abs(pout)/2e-5);

%level in the box
pudb= 20*log10(abs(pin)/2e-5);

%level in the near field
pnfdb= 20*log10(abs(pnf)/2e-5);

semilogx(f,pudb),title('SPL (dB)  inside the box'),grid,pause
semilogx(f,pnfdb),title('SPL (dB) in near field'),grid,pause

subplot(221);
echo off;
semilogx(f,pdb),title('SPL (dB/2pi)'),grid;
xlabel('f (Hz)');
subplot(222);
semilogx(f,abs(xuk)*1000),title('Displacement (mm) '),grid;
xlabel('f (Hz)');
subplot(223);
semilogx(f,angle(pout)*180/pi),title('Phase (deg) '),grid;
xlabel('f (Hz)');
subplot(224);
semilogx(f,abs(zul)),title('Impedance (ohm)'),grid;
xlabel('f (Hz)'), pause;
subplot;
```

Appendix 2 – Measuring distortion of microphones

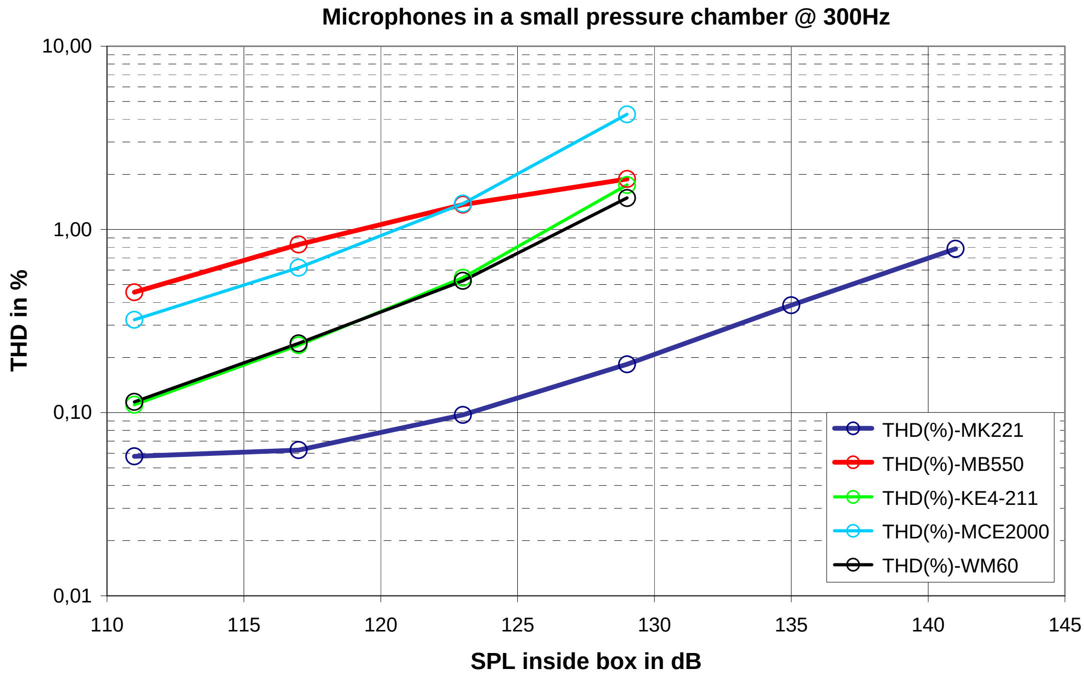


Figure A1: Relative comparison of distortion of microphones at 300 Hz