ARTA-Tutorial: Parameter Measurement on Passive Radiators

1.0 Preface

The use of passive radiators - hereafter also called PR - instead of bass reflex tubes is always appropriate, for example, when small cabinets are to be tuned very low. PR have the reputation of easy handling/tuning and avoiding "midrange garbage". Negative are the costs and the higher losses compared to the classic bass reflex tube.

The basics of bass reflex loudspeakers with passive radiators are discussed in detail in [01] and [02]. They differ from classical bass reflex systems mainly by an additional pole, caused by the compliance of the passive radiator. Figure 1 shows both variants in direct comparison.

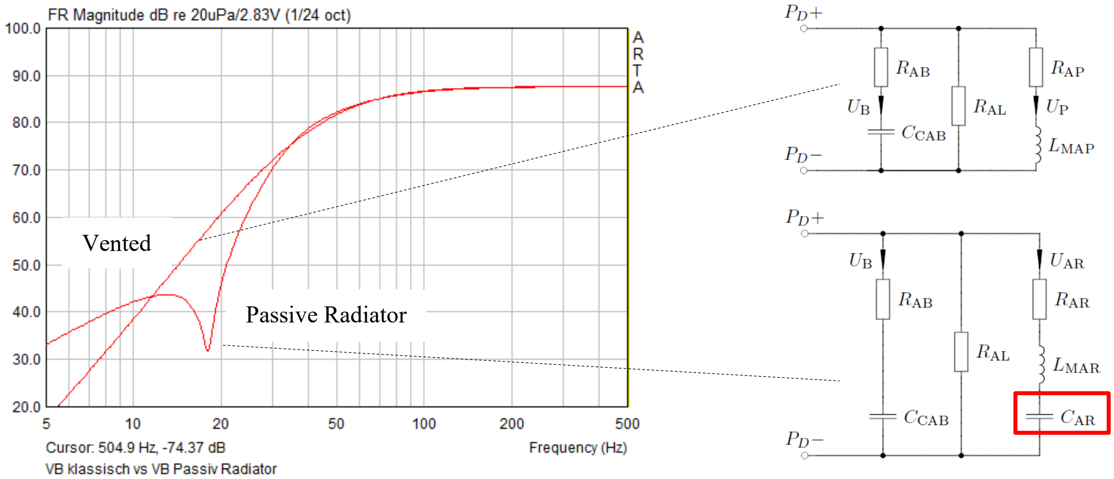


Figure 1: Classic bass reflex vs. passive radiator [06]

For the simulation/tuning of the loudspeaker it is important to know also the parameters of the PR. For most commercially available PR, the manufacturers provide the necessary data. If this is not the case, only trial and error or self-measurement will help. When using the manufacturer's data, it is noticeable that simulated and measured impedance curves often do not match (see e. g. Fig. 4). What could be the reason for this?

a) The simulation model used does not reflect reality,
b) the impedance measurement is faulty,
c) the parameters of the PR are wrong.

The author assumes that a) and b) are rather improbable as causes of error in the small-signal range and thus only c) can be considered as the culprit, and you end up measuring the PR parameters on one's own.

Literature searches on the measurement of PR parameters are not very productive. The search yields a rather "historical" paper from Speaker Builder [05] and finds on Klippel's homepage [03] and [04]. In [04] the determination of PR parameters by means of the Klippel system based on MicInBox measurements is described in detail.

The parameters required for the simulation are: fs, M_{mp}, C_{mp}, V_{ap}, S_{dp}, Q_{mp}, R_{mp} and X_p. Of these, f_s, M_{mp}, C_{mp}, V_{ap} and S_{dp} can be measured or calculated relatively easily using onboard tools, while Q_{mp} requires the use of a suitable laser [07] to measure the excursion or can be determined indirectly using a suitable simulation program (VituixCAD). Regarding the determination of X_p, please refer to [07].

Since the measurement of the excursion by means of a laser is not accessible to most DIYers, the description of the determination of the Q_{mp} according to [04] is moved to Appendix 1. In the following, the measurement of the basic parameters is first explained and then the way to determine Q_{mp} or R_{mp} by means of impedance measurement and VituixCAD.

2.0 Measurement setup and execution of the measurements

In addition to ARTA and LIMP, a test enclosure, a microphone and the simulation program VituixCAD - hereinafter referred to as VCAD for short - are required for the measurement. The dimension of the baffle of the test enclosure should be adjusted to the maximum diameter of passive membranes to be measured. For the volume of the test enclosure it is recommended to adjust it to the used active driver (optimal bass reflex enclosure). In addition, the test enclosure requires a hole for inserting the measurement microphone (see Fig. 2), but attention must still be paid to tightness.

The following measurements must be carried out to determine the parameters:

a) SPL in the cabinet with PR without additional mass (M_{ad} = 0,0g)
b) SPL in the cabinet with PR with precisely determined additional mass M_{ad} > 0,0g
e) Measurement of the impedance response (M_{ad} = 0,0g)

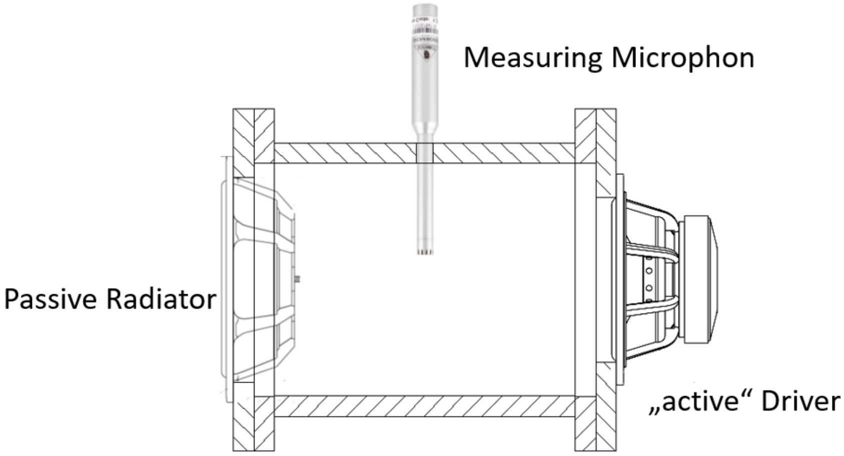


Figure 2: Measurement setup for parameter determination

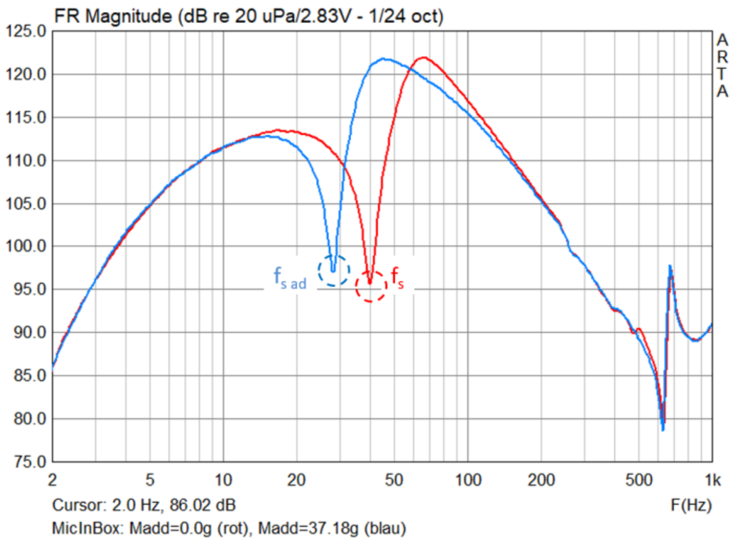


Figure 3: SPL in the cabinet with additional mass (blue), without (red)

The resonant frequency of the passive radiator f_s results from the measurement without additional mass (see Fig. 3, red curve). The blue curve in Fig. 3 shows the resonant frequency f_{sad} with additional mass. With these two values, the first parameters of the PR can be calculated (see formula 1 to 3). Since the sound pressure in the enclosure can be very high during these measurements, attention must be paid to the excitation level so that the microphone is not overloaded.

$$\boldsymbol{Mmp} = \frac{Mad}{\left(\frac{fs}{fs\ ad}\right)^2 - 1} \quad (01)$$

$$\boldsymbol{Cmp} = \frac{1}{4 \cdot \pi^2 \cdot fs^2 \cdot Mmp} \quad (02)$$

$$\boldsymbol{Vap} = p \cdot c^2 \cdot Cmp \cdot SD^2 \quad (03)$$

$$\boldsymbol{Qmp} = \frac{fs}{fh - fl} \quad (04)$$

$$\boldsymbol{Rmp} = \frac{2 \cdot \pi \cdot fs \cdot Mmp}{Qmp} \quad (05)$$

f_s = resonance frequency without additional mass in Hz
f_{sad} = resonance frequency with additional mass in Hz
M_{ad} = additional mass in kg
M_{mp} = radiator mass of the passive radiator in kg
C_{mp} = compliance of the passive radiator in m/N
V_{ap} = equivalent volume of the passive radiator in m^3
S_D = eff . Radiator area of the passive radiator in m^2
p = 1.18 kg/ m^3
c = 344 m/s
Q_{mp} = mechanical quality of the passive radiator
f_h = see picture # in Annex 1
f_l = see picture # in Annex 1
R_{mp} = mechanical resistance of the passive radiator in Ns /m

For the example measured in Figure 3 (DS175PR), this results with

S_D = 128,7cm2 = 0,01287m2
fs = 39,5Hz →*(24,5Hz)*
f_{sad} = 28,2 Hz with M_{ad} = 37,18 g
M_{mp} = 0,03718 / (39,5 / 28,2) ^{2} - 1 = 0,03865 Kg = 38,65g →*(36,6g)*
C_{mp} = 1 / (4 · π ^{2} · 39,5 ^{2} · 0,03865) = 0,00042 m/N = 0,42 mm/N →*(1,15 mm/N)*
V_{ap} = 1,18 · 344 ^{2} · 0,00042 · 0,01287 ^{2} = 0,00971 m ^{3} = 9,71 L →*(27,1 L)*
Q_{mp} = 12,74 (5,57)→ ***for determination see Annex 1***
R_{mp} = 2 · π · 39,5 · 0,03865 / 12,74 = 0,75 Ns /m (n.a.)

The determined parameters differ significantly from the manufacturer's specifications (*see → values in brackets*). The determination of the parameters is largely independent of the active driver used and the volume of the test enclosure (see also Annex 1).

3.0 Determination of Q_{mp} with VituixCAD

To determine Q_{mp}, we enter the VCAD simulation program with the known or measured PR parameters and the measured Thiele Small Parameters of the active driver. Since version 2.0.99.0, an optimization routine for determining the parameters of passive radiators has been integrated into the " *Enclosure"* tool in VCAD. This opens up an alternative path for those who do not have access to a laser. With an arbitrarily assumed starting value for Q_{mp} between 3 and 7 - if not known from the specification - and the measured and imported impedance curve, the simulation starts.

As initial values for the losses, the guide values given below by Richard Small in [02] can be used:

Absorption loss	Q_A - typically 100 or more
Leakage loss	Q_L - between 5 and 20
Port loss	Q_P - between 50 and 100

The port losses in systems with a passive radiator can be much higher. Values of 5 – 50 are found in the literature (Q_{mp} is the equivalent of Q_P).

The procedure for determining the PR parameters in VCAD [08] is as follows:

1) Select in VCAD in the tool "*Enclosure*" the Radiator type "*Passive Radiator*".
2) Load the current TS-Parameters for the active driver from the VCAD driver database and enter the volume of the test enclosure and the recommended values for Ql and Qa.
3) Load - if available - the parameters of the PR from the VCAD driver database. If no data is available, go to section 2.
4) Import the impedance measurement of the PR system via "*Open Overlay*" (see Figure 4)
5) Start the optimization process with "*Solve*" and select the parameters to be optimized.
6) Check the optimization result for plausibility and, if necessary, correct the PR parameters in the VCAD driver database with the optimized values.

To illustrate the procedure described, the following variants are shown in comparison to the measured data and the resulting PR parameters:

a) simulation with the manufacturer data,
b) Simulation with the manufacturer data optimized by VCAD,
c) Simulation with the parameters determined acc. to Section 2,
d) Simulation with the parameters determined acc. to Section 2 + Q_{mp}, Q_a, Q_l optimized by VCAD.

The reference value for the VCAD optimization is the **measured** impedance response.

a) Comparison simulation manufacturer information - measurement

Figure 4 shows the comparison of the simulation based on manufacturer data (blue) with the measured data (red). The parameters used can be found in the left part of the figure (*Note: Q_{ms} in the Passive area corresponds to Q_{mp}*). Obviously there are relatively large differences between measurement and simulation.

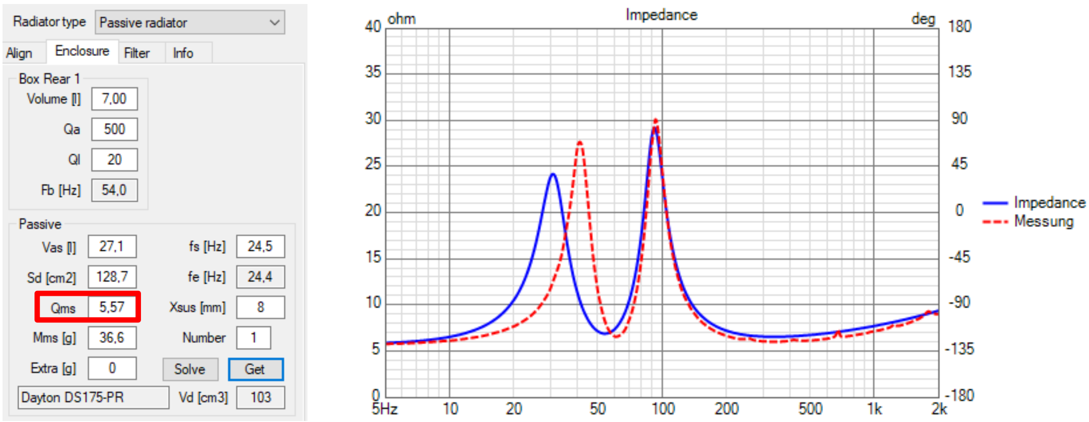


Figure 4: Comparison of simulation (blue) and measurement (red): Impedance
Simulation with manufacturer data

To illustrate the effect of this difference, Figure 5 additionally shows the comparison between measured near-field level (SPL) normalized to 1.0 meter and the excursion with the simulation based on the manufacturer's data. The red curves represent the measured values in each case. The tuning frequency differs by 4-5 Hz (see green circle) and measurement and simulation also differ significantly in excursion.

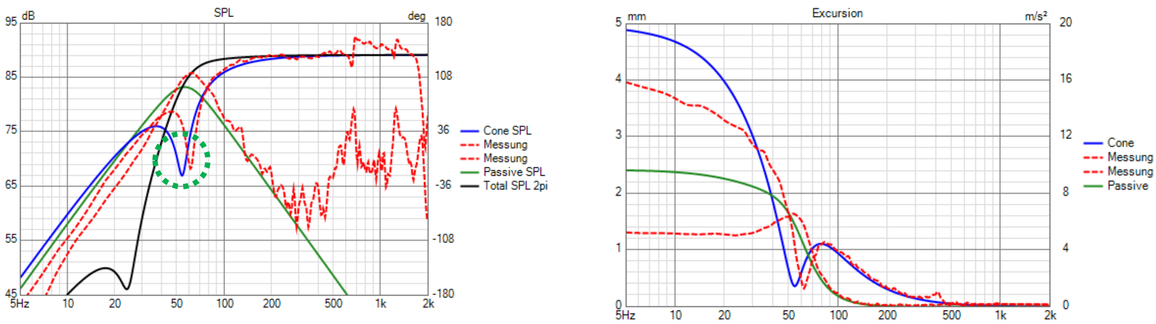
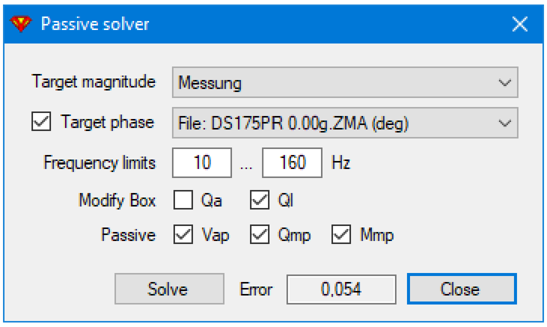


Figure 5: Comparison of simulation and measurement (red): SPL, excursion
Simulation with the manufacturer data

b) Comparison simulation VCAD optimized manufacturer specifications - measurement

In this section, we will now show what is changed by "optimizing" the PR parameters and the loss factors (Qa, Ql) of the overall system using VCAD. The measured impedance curve of the system is used as the reference variable for the optimization. However, the measured near-field frequency response from the membrane of the active driver and the PR are still observed.

To do this, we use the "P*assive solver* " in VCAD's Enclosure tool to match the measured impedance with the simulation.



If activated (see Figure on the left), all losses as well as V_{ap} and M_{mp} are included as variables in the optimization process. The resonant frequency f_{sp} is fixed, so it is not used in the optimization process.

This means that the optimization process will correct erroneous initial values of f_{sp} via the radiator mass M_{mp} of the PR. Therefore, a verification of the resonance frequency f_{sp} of the PR according to Section 2 is always recommended in advance of the simulation.

The result of the optimization is shown in Figure 6. Measurement and simulation are now in good agreement regarding impedance.

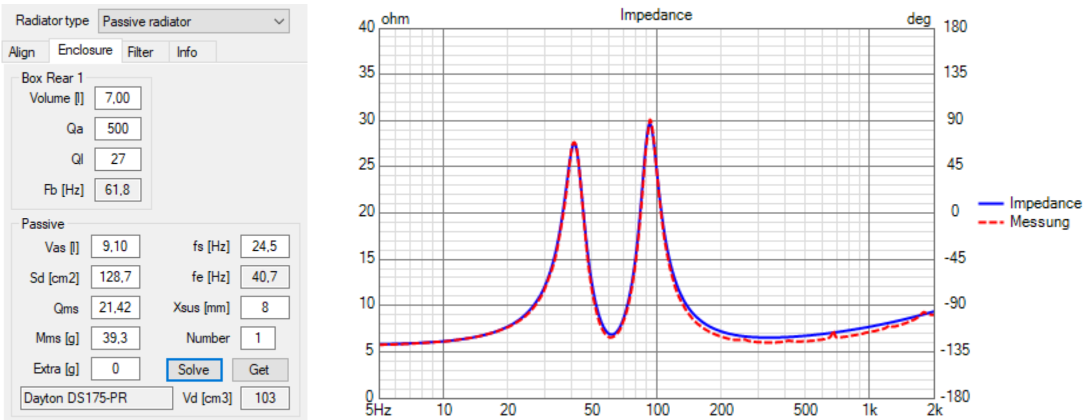


Figure 6: Parameters after the optimization of the manufacturer's data
red = measurement, blue = simulation with optimized manufacturer's data

What has changed now regarding SPL and excursion compared to the measurement? Figure 7 shows that the simulation is now in much better agreement with the measured data. Both the tuning frequency and the excursion now match (compare with Figure 5).

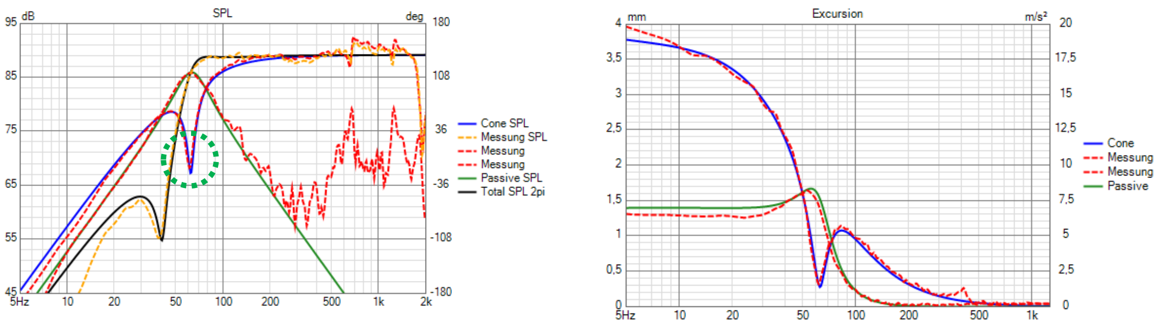


Figure 7: Comparison of simulation and measurement after optimization of manufacturer's data with VCAD

c) *Comparison of simulation with the parameters determined acc. to Section 2 - Measurement*

As can be seen from the data at the end of section 2, measured values and values specified by the manufacturer differed significantly, as did the resonant frequency. Figure 8 and Figure 9 show the comparison of the simulation with the parameters measured according to section 2 and the measurements (red) **without** VCAD optimization.
Without any VCAD optimization, there is already good agreement between simulation and measurement. The parameters determined are summarized in Table 1. Further VCAD optimization is expected to yield only minor improvements (see section d below).

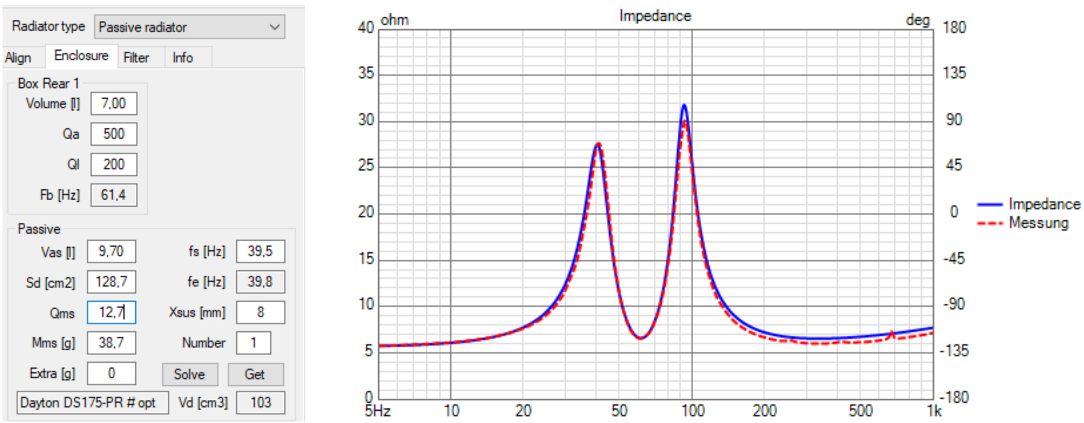


Figure 8: Comparison of simulation (blue) and measurement (red): Impedance red = measurement, blue = simulation with measured parameters

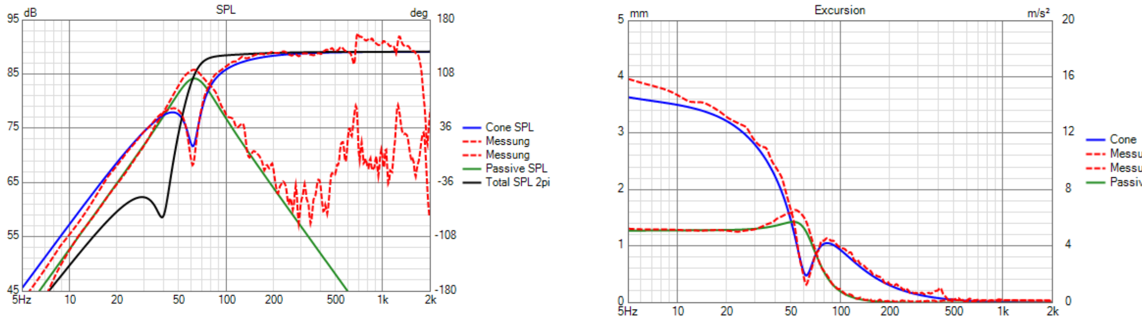
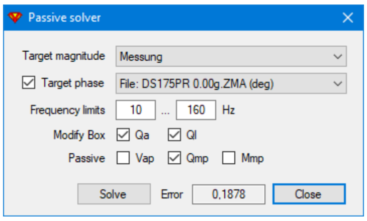


Figure 9: Comparison with measured parameters according to Section 2, SPL, excursion red = measurement, blue = simulation with measured parameters

d) Comparison of simulation with the parameters determined acc. to Section 2 + VCAD optimization - measurement



Apparently, measurement and simulation are closer together with the measured parameters than with the manufacturer's data (compare Figure 4 / Figure 5 with Figure 8 / Figure 9).

Since Ql and Qa were arbitrarily chosen in this simulation based on the initial recommendations given, Qa, Ql, and Q_{mp} are sub-sequently optimized using VCAD and thus activated as a variable in the "*Passive Solver*". The result of this optimization is shown in Figure 10 and Figure 11.

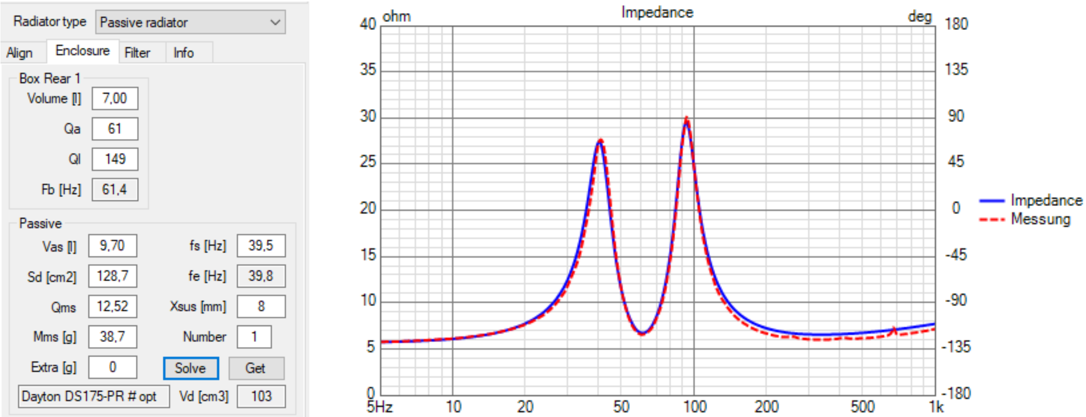


Figure 10: Comparison of simulation (blue) and measurement (red): Impedancered = measurement, blue = simulation with measured parameters, VCAD optimized

As expected, the VCAD optimization only brought minor improvements to the parameters. This can be seen most clearly in the excursion (Figure 11, right).

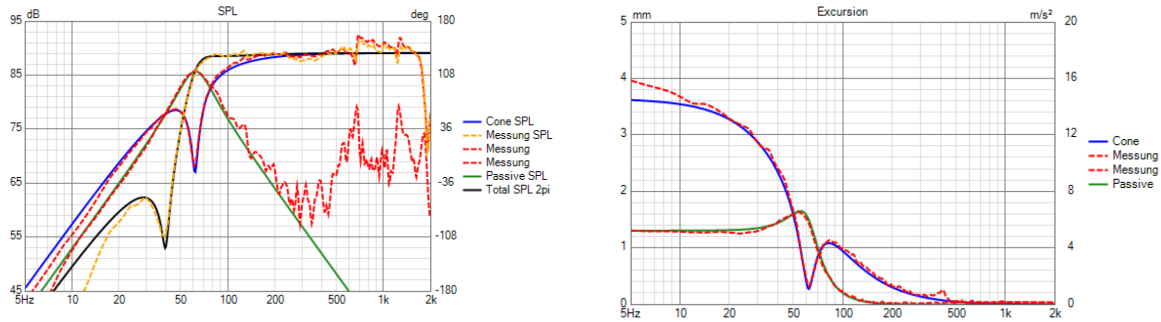


Figure 11: Comparison of simulation and measurement: SPL, excursion
red = measurement, blue = simulation with measured parameters, VCAD optimized

Conclusion on the measurement/optimization: The comparison of Fig. 6/7 and Fig. 10/11 shows that variant b) and variant d) are visually roughly equivalent. However, the values in Table 1 do show differences between variants b, c and d.

Parameter	manufac-turer data	VCAD optimization manufacturer data	measured data	VCAD optimization measured data	
Variant	a	b	c	d	
Q_a	500*	375	**500***	72	73
Q_l	20*	195	**20***	81	83
f_s (f_{sp})	24.5	24.5 (fix)	**39.5**	39.5 (fix)	39.5 (fix)
V_{as} (V_{ap})	27.1	9.30	**9.71**	9.71 (fix)	9:12
M_{ms} (M_{mp})	36.6	38.4	**38.65**	38.65 (fix)	39.2
Q_{ms} (Q_{mp})	5.57	24.50	**12.74**	12.52	13:18

Note: ** Freely selected starting values, fix = values are not available for optimization*

Table 1: Determined PR parameters in comparison with the manufacturer's data

It seems plausible to the author that the variants using the individually measured parameters are likely to provide the more realistic results. Irrespective of this, all variants are closer to the measured reality than the simulation using the manufacturer's data. This was confirmed by examining other passive radiators (see Annex 2).

It is therefore advisable not to apply the manufacturer's specifications uncritically. In the end, an impedance measurement and a short VCAD optimization can be coped in terms of effort.

4 .0 Maximum Linear Excursion

To complete the data set, the maximum linear excursion is still missing. This can be determined following the procedure described in [07] (dynamic X_{lin} determination). An alternative method is to load the passive diaphragm with different weights and measure the respective excursion (quasi-static X_{lin} determination).

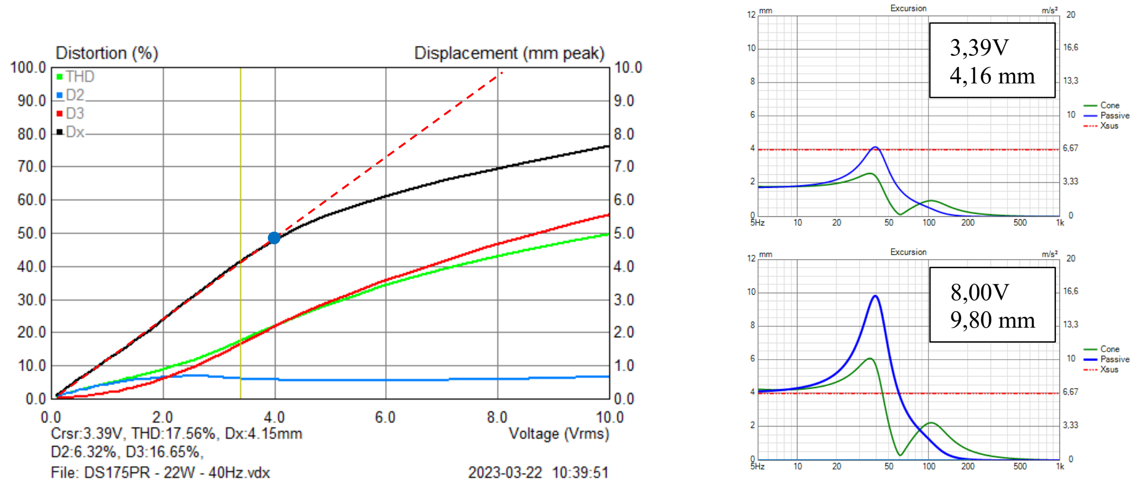


Figure 12: Measurement of the linear excursion compared to the simulation

Figure 12 shows the result of the displacement measurement using **STEPS – Distortions and Displacement** in comparison with the simulation. The measurement was made at 40 Hz, the frequency with the highest excursion of the PR.

The blue dot on the left shows the measured maximum linear displacement of approx. 4.8 mm. According to the manufacturer, it should be 8 mm, he probably forgot to mention "peak-peak" in the specification.

This example also shows the limits of simulations very nicely. While in the linear range - here at 3,39V for example - measurement and simulation for the excursion are in good agreement, at 8,0 V it no longer fits at all. Here the measurement shows a excursion of approx. 7,0 mm and the simulation 9,8 mm. It is not without reason that the models based on the Thiele Small Parameters only apply to the small-signal range, since non-linearities are not taken into account in the model.

Note: For dynamic displacement measurements, it is important to note that the linear displacement volume V_D of the active driver must be significantly larger than that of the PR. The active driver used for the measurements in Figure 13 and Annex 2, respectively, has a V_{Dlin} of 268 cm^3 and a V_{Dmax} of 564 cm^3. This results approximately in the maximum possible deflections shown in the following table for the PMs mentioned.

			V_{Daktiv} [cm^3]	
Typ	Herstellerdaten		268	564
	X_{max} [mm]	S_D [cm^2]	X_{lin} Peak [mm]	X_{max} Peak [mm]
DS135PR	4,0	75,4	17,8	37,4
SDS P380880	k. Angabe	87,0	15,4	32,4
SB16PFCR	5,0	124,0	10,8	22,7
DS175PR	4,0	128,7	10,4	21,9
SP18R	9,5	130,0	10,3	21,7

In the case of the small passive radiator with S_D = 75,4 cm^2 with 17,8 mm there is obviously sufficient linear travel reserve in relation to the manufacturer's specifications for X_{max}. In the case of the SP18R, the linear excursion of 10,3 mm is just enough to extend the PR with X_{max} = 9,5 mm. However, this is a worst-case scenario, because at the frequency at which the PR deflects maximum, there is still a reserve if the active driver is selected appropriately (see Figure 12, right-hand Figures, cone = green line).

In principle, the static determination of the excursion is relatively simple. The radiator is weighed down with a known mass M_{add} and the resulting excursion X is measured, for example with a depth gauge. Nuts of size M14 (approx. 20 g) to M20 (approx. 52 g) are suitable as masses. However, care should be taken not to impose too much on the diaphragm when making these measurements. If the manufacturer's specifications for X_{lin} and C_{ms} are available, it is possible to estimate the point at which the linear range is exited. For the candidate discussed here as an example, this should be around 8.9 N or 900 grams.

$$F = \frac{x[mm]}{Cms[mm/N]} = \frac{4}{0{,}45} = 8{,}9\ N \rightarrow \frac{8{,}9}{9{,}81} = 0{,}91\ Kg$$

Figure 15 shows the excursion with load steps of 52g and from 4.0 N with 42g up to a load of 10 N (blue line with circle). The result obviously differs significantly from that in Figure 13, where the linear range goes up to approx. 4.8 mm. What could be the reason for this?

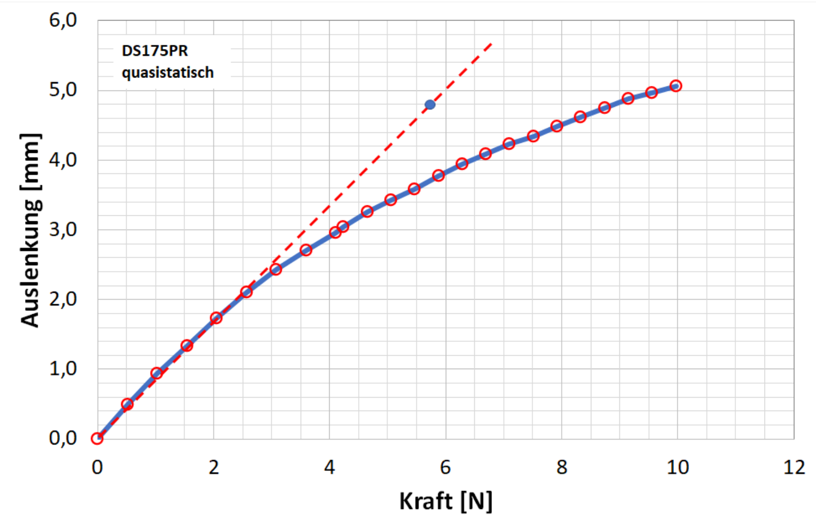


Figure 13: Measurement of the excursion with weights (quasi-static)

The speed of loading or the frequency can be used as an explanation. While the excursion in Figure 13 was measured quasi-statically, in the dynamic case (Figure 12) it was exactly 40 Hz, which corresponds to the maximum excursion of the PR. If one compares the dynamic excursion measured at 23 Hz (blue) with the static excursion (black) in Figure 14, there is extensive congruence. Further details can be found in Annex 3.

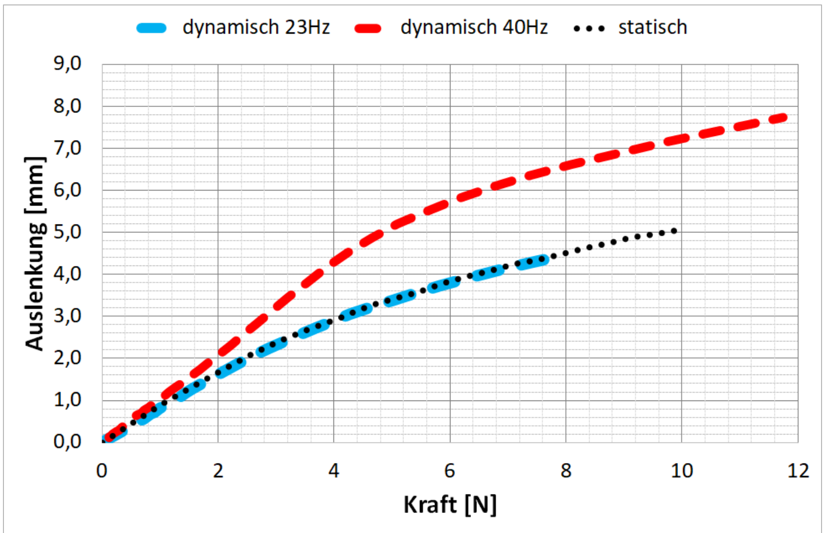


Figure 14: Comparison of the dynamic and the quasi-static measurement

From the measured static deflection curve in Fig. 13, C_{ms} can be determined. For our candidate DS175PR, C_{ms} is obtained in the linear range for approx. 0.208 kg load (corresponds to 4 M20 nuts) as follows:

$$\boldsymbol{Cms} = \frac{x\,[m]}{F\,[N]} = \frac{x\,[mm]}{M_{add}\,[Kg]\, \times\, 9{,}81\,[N/Kg]} = \frac{1{,}73}{0{,}208\, \times 9{,}81} = 0{,}85\,\frac{mm}{N}$$

The table below shows the comparison between manufacturer data, the determination of C_{ms} according to Section 2, formula (2) and the static measurement. In the C_{ms} dynamic column, the first item was measured at the beginning of the test series and the second item together with the static measurement. The differences are due to the different levels of stress on the measurement objects in the meantime, as well as the static ones Measurements by the time-dependent to explain creep processes. Picture 13 shows this very clearly for our candidates. Initially amounts to C_{ms} = 1,73/2,04 = 0,85 mm/N at the end of the cumulative loading Cms = 5,06 / 9,97 = 0,51mm/N.

PR	C_{ms} [mm/N] Manufacturer	C_{ms} [mm/N] dynamic	C_{ms} [mm/N] quasi-static	C_{ms} [mm/N] static
DS135PR	1,52	1,35 / 1,21	1,15 – 1,29	1,32-1,37
SB16PFCR	1,40	1,19 / 1,23	1,14-1,30	1,16-1,20
SP18R	2,02	1,09 / 1,24	1,25-1,27	1,22-1,25
SDS P830880	0,72	0,84 / 0,79	0,87 – 0,90	0,87 – 0,90
DS175PR	**0,45**	**0,45 / 0,56**	**0,51 – 0,68**	**0,64 – 0,66**

Note: *dynamic = STEPS, quasi-static = stepped load, static = creep test*

Table 3: Comparison C_{ms} static/dynamic

One way of demonstrating creep processes in the bead or the suspension of the PR is the creep test. In the test, the PR is loaded with a constant force and the excursion is measured. Fig. 15 shows the result for the DS175 PR as an example. The evaluation of all creep tests is shown in Annex 3.

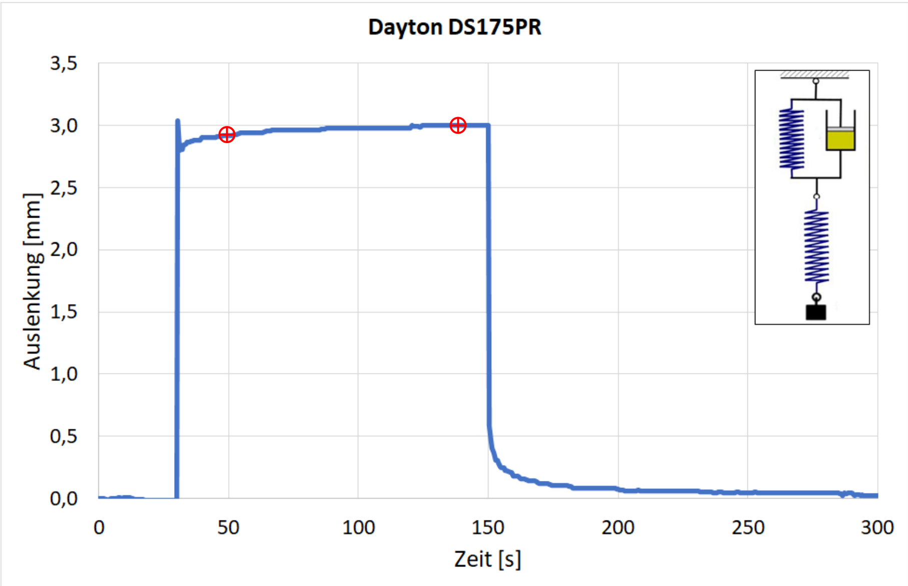


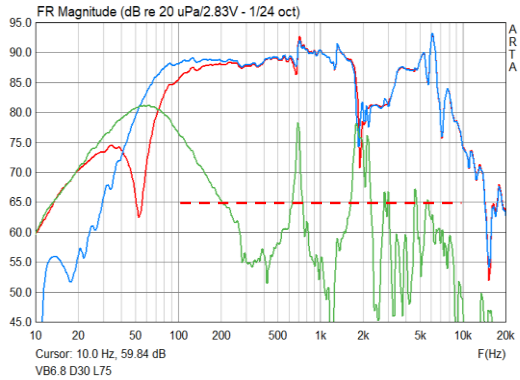
Figure 15: Creep test with 4.57 N (static)

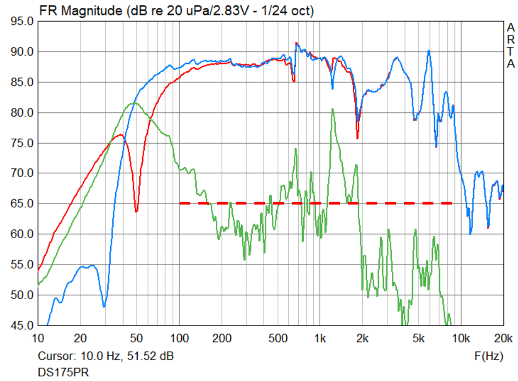
Looking at the time axis of Fig. 15, it is clear, of course, that the creep test does not correspond to the loading case of a PR bead, but it still makes clear that the PR suspension cannot be explained by Hook's law alone. C_{ms} can also be derived from Fig. 15. For a load of 4,57 N and a excursion of 2,92 mm to 3,03 mm, the C_{ms} is 0,64 to 0,66 mm/N.

5.0 Last but not least

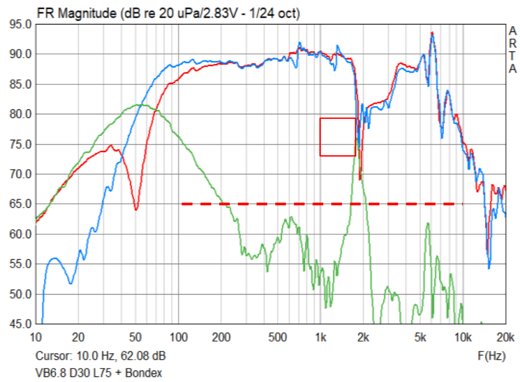
Finally, two more notes. **First:** Figure 16 shows a comparison between a PR system and a classic bass reflex system (empty vs. damped). Both systems are tuned to $f_b = 51$Hz. The analysis of the resonances in the test enclosure gives the following frequencies: 686, 1008, 1220, 1372, 1426, 1583, 1703, 1979, 2018, the reflex tunnel resonance is 1711 Hz.

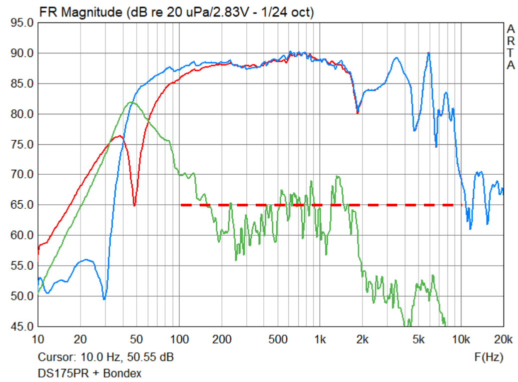
Bass reflex, classic | **Passive Radiator**





Enclosure empty | Enclosure empty





Enclosure filled with 0.12m^2 Bondum | Enclosure filled with 0.12m^2 Bondum

Figure 16: Comparison of a conventional bass reflex box (left) with a system with a passive radiator (right)

It can be clearly seen that even with speakers equipped with passive radiators, the leakage of "midrange garbage" cannot be prevented per se. Nevertheless, there is a striking difference between reflex tunnel and PR. While the PR version already looks quite calm after damping the cabinet with approx. 0.12 m^2 Bondum, a fierce resonance can still be measured at the reflex tunnel.

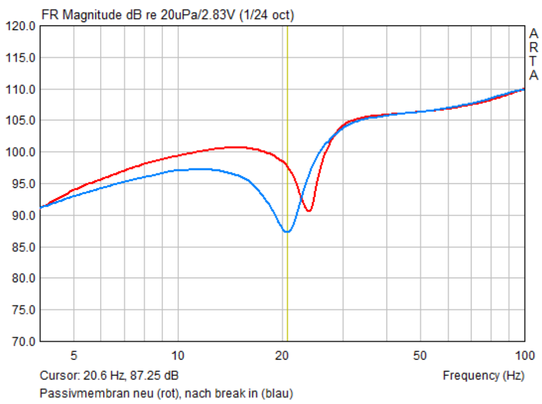


Figure 17: Resonance shift due to burn in

Second: When measuring the PR-parameters, it should be noted that passive radiators also need a "burn in". Figure 17 shows an example of the resonance shift after a pre-treatment of approx. 20 minutes at high excursions.

6.0 Literature

[01] R. H. Small: Passive -Radiator Loudspeaker Systems, Part I: Analysis; JAES 10/1974

[02] R. H. Small: Passive-Radiator Loudspeaker Systems, Part II: Synthesis; JAES 11/1974

[03] W. Klippel: Dynamical Measurement of Loudspeaker Suspension Parts,
AES Convention Paper 6179, 2004

[04] W. Klippel: AN 57 - Parameter Measurement of Passive Radiators

[05] G. R. Koonce: Finding f_p for Passive Radiator Speakers, Speaker Builder 04/1981

[06] J. Ahonen : Electroacoustic modeling of subwoofer enclosures, 2007

[07] I. Mateljan , H. Weber: AP7 - Determination of the linear excursion with STEPS

[08] K. Saunisto - VituixCAD (https://kimmosaunisto.net/Software/VituixCAD)
Help File: " solving parameters of passive radiator "

[09] R. H. Small: Simplified Loudspeaker Measurements at low Frequencies; JAES 02/1972

[10] J. D'Appolito : Measuring Loudspeaker Low-Frequency Response; audioXpress 06/2012

HWe, 07.04.2023

ANNEX 1

Determination of Q_{mp} of the passive radiator

As announced in section 2, the determination of the mechanical quality Qmp of the passive radiator according to [04] shall be described here. Since the PR is driven by the pressure generated by the active driver, the mechanical Q can be determined from the quotient Hx(jω) of the course of the diaphragm excursion x(jω) to the sound pressure in the test enclosure p(jω) (see Fig. 18). This requires a laser, a microphone and the measurements mentioned below:

a) Measurement of the sound pressure in the test enclosure (MicInBox)
b) Measuring the excursion of the PR using a laser

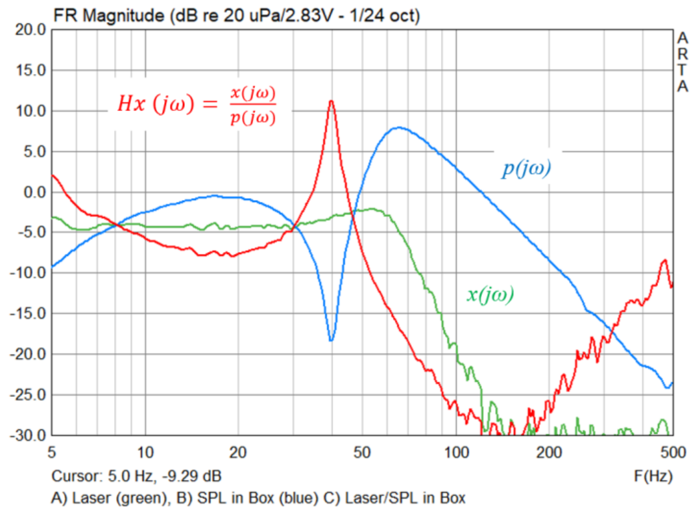


Figure 18: A) Excursion of the passive radiator (green),
B) SPL in the enclosure (blue), quotient of A/B (red)

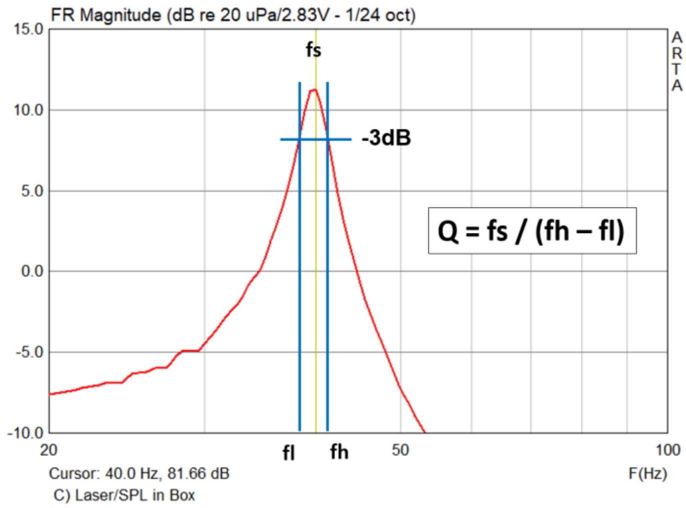


Figure 19: Determination of Q_{mp} from the quotient A/B

With f_s = 39,50 Hz, f_l = 38,30 Hz and f_h = 41,40 Hz, the resulting Q_{mp} is 12,74. With this, the last parameter R_{mp} can be calculated.

$$Rmp = \frac{2 \cdot \pi \cdot fs \cdot Mmp}{Qmp} = \frac{2 \cdot \pi \cdot 39{,}5 \cdot 0{,}03865}{12{,}74} = 0{,}75\ Ns/m$$

The course of the quotient from A/B is largely independent of the choice of active driver and the size of the test enclosure, as the two following investigations show.

Dependency on the active driver

Determination of the parameters of the passive radiator DSA215PR with 4 different "active" drivers (Monacor SPH130, SB Acoustics SB15NAC30-8, Omnes BB3AL, Westra SW200-1308). The measured passive radiator has a S_D of 211 cm^2. Although the results of the excursion measurement (Fig. 20a) and the MicInBox measurement (Fig. 20b) are obviously strongly influenced by the active driver, this is not evident at Hx(jω) (Fig. 20c). This confirms an independence from the active driver.

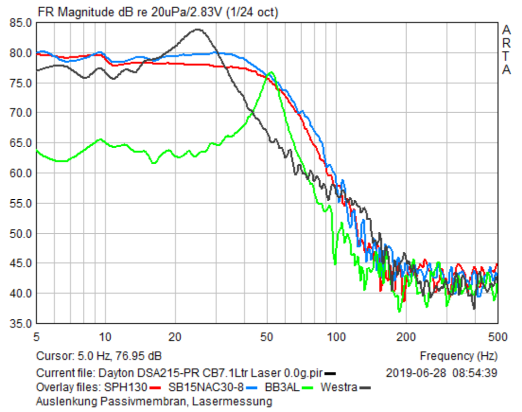


Figure 20a: Excursion PR, laser measurement x(jω)

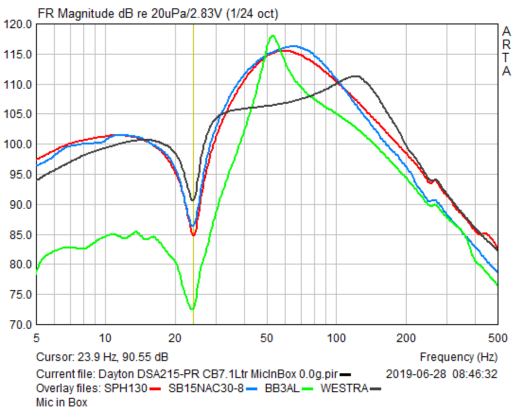


Figure 20b: SPL in Box (MicInBox) →p(jω)

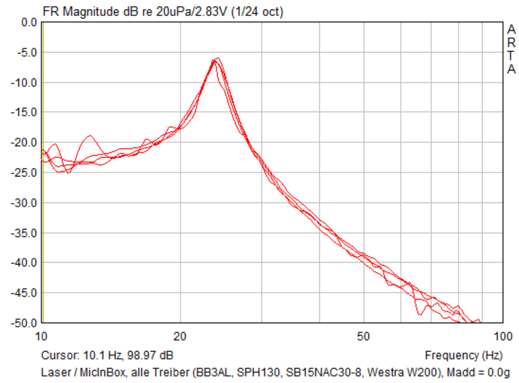


Figure 20c: $Hx\ (j\omega) = \frac{x(j\omega)}{p(j\omega)}$

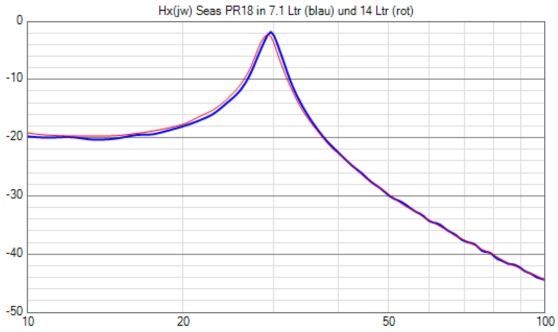
Figure 20: Determination of the Q_{mp} with different active drivers

The following table shows the evaluation of all results. Except for one outlier when using the very small BB3AL broadband loudspeaker, all the data determined are within the scope of the expected measuring accuracy.

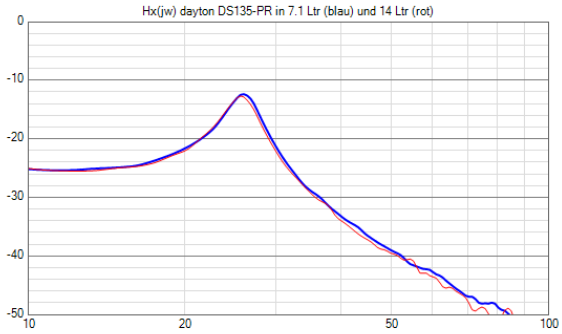
Active drivers	M_{Add} [g]	f_s [Hz]	M_{mp} [g]	C_{mp}[mm/N]_	V_{ap} [l]	Q_{mp}
SPH130	0,00	**24,0**				9,98
S_D = 81,4cm2	28,94	20,8	87,3	0,50	31:4	12,97
	42,15	19,3	77,1	0,57	35,5	12,06
SB15NAC30-8	0,00	**23,7**				10,57
S_D = 82cm2	28,94	20,6	89,4	0,50	31:4	12,87
	42,15	19,3	83,0	0,54	33,8	12,95
BB3AL	0,00	**23,9**				~~21,31~~
S_D = 31cm2	28,94	20,5	81,9	0,54	33,9	11,44
	42,15	-	-	-	-	-
Westra SW200	0,00	**23,7**				11,32
S_D = 201cm2	28,94	20,5	86,0	0,52	32,7	11,44
	42,15	19,3	83,0	0,54	33,8	11,35
Average		23,83	83,46	0,53	33,4	11,70

Dependence on the size of the test enclosure

Figure 21 $Hx(j\omega)$ shows the curve of for two different passive radiators in a 7,0 dm^3 (blue) and a 14,0 dm^3 test enclosure (red). Here, too, there seems to be little or no dependency.



Seas PR 18 in 7,0 liters (blue) and 14,0 liters (red)

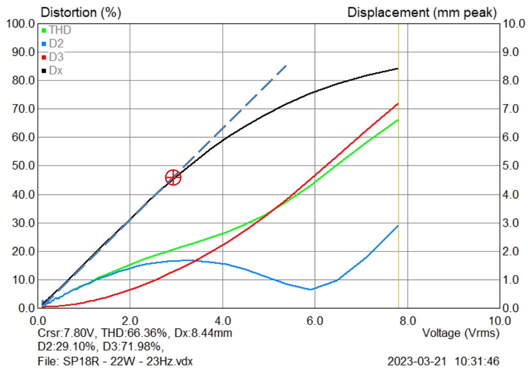


Dayton DS135-PR in 7,0 liters (blue) and 14,0 liters (red)

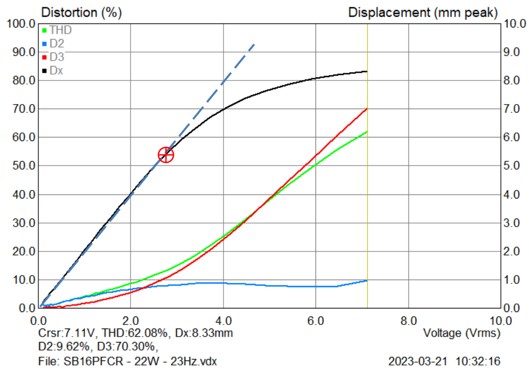
Figure 21: $Hx(j\omega)$ for two different passive radiators in different test enclosures

ANNEX 2

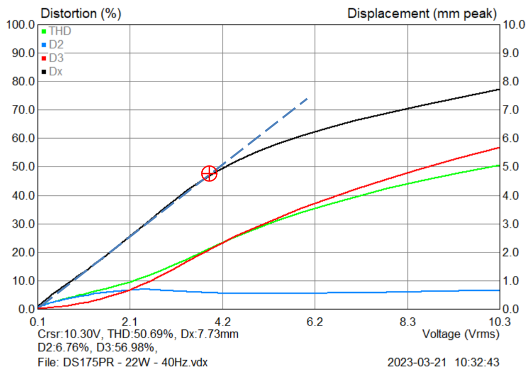
Measurement of linear displacement with STEPS, results



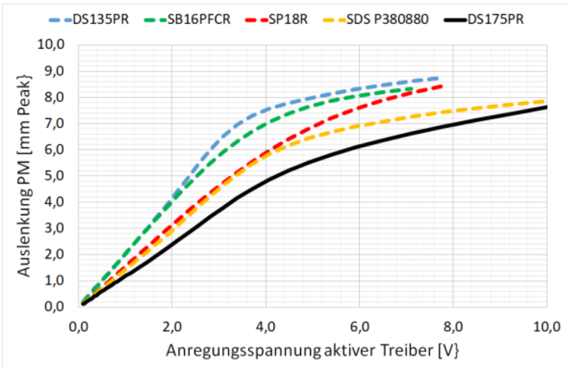
SP18R – 4,5mm (9,5mm)



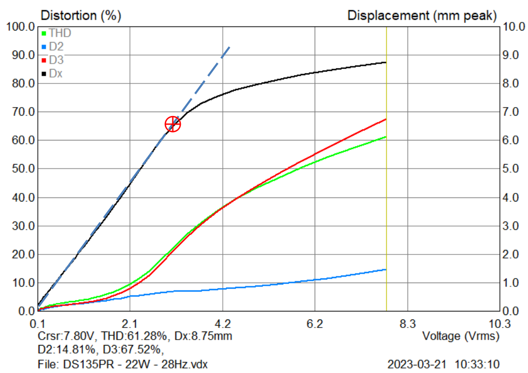
SB16PFCR – 5,4mm (5,0mm)



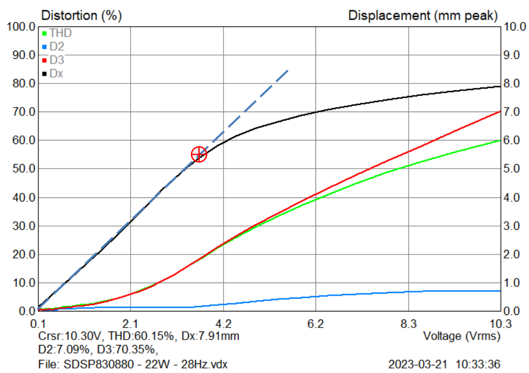
DS175PR – 4,7mm (4,0mm)



Summary presentation



DS135PR – 6,5mm (4,0mm)



SDSP830880 – 5,5mm (n. a.)

Note 1: *Values in brackets are manufacturer's specifications*
Note 2: *All measurements were performed at 40 Hz, the maximum excursion of the PR*
Note 3: *The following termination criteria were specified for the measurement:*
10,3 V or 60% THD (green)

Figure 22: Measurement of the linear excursion with STEPS according to [07]

ANNEX 3

Dynamic/static measurement analysis

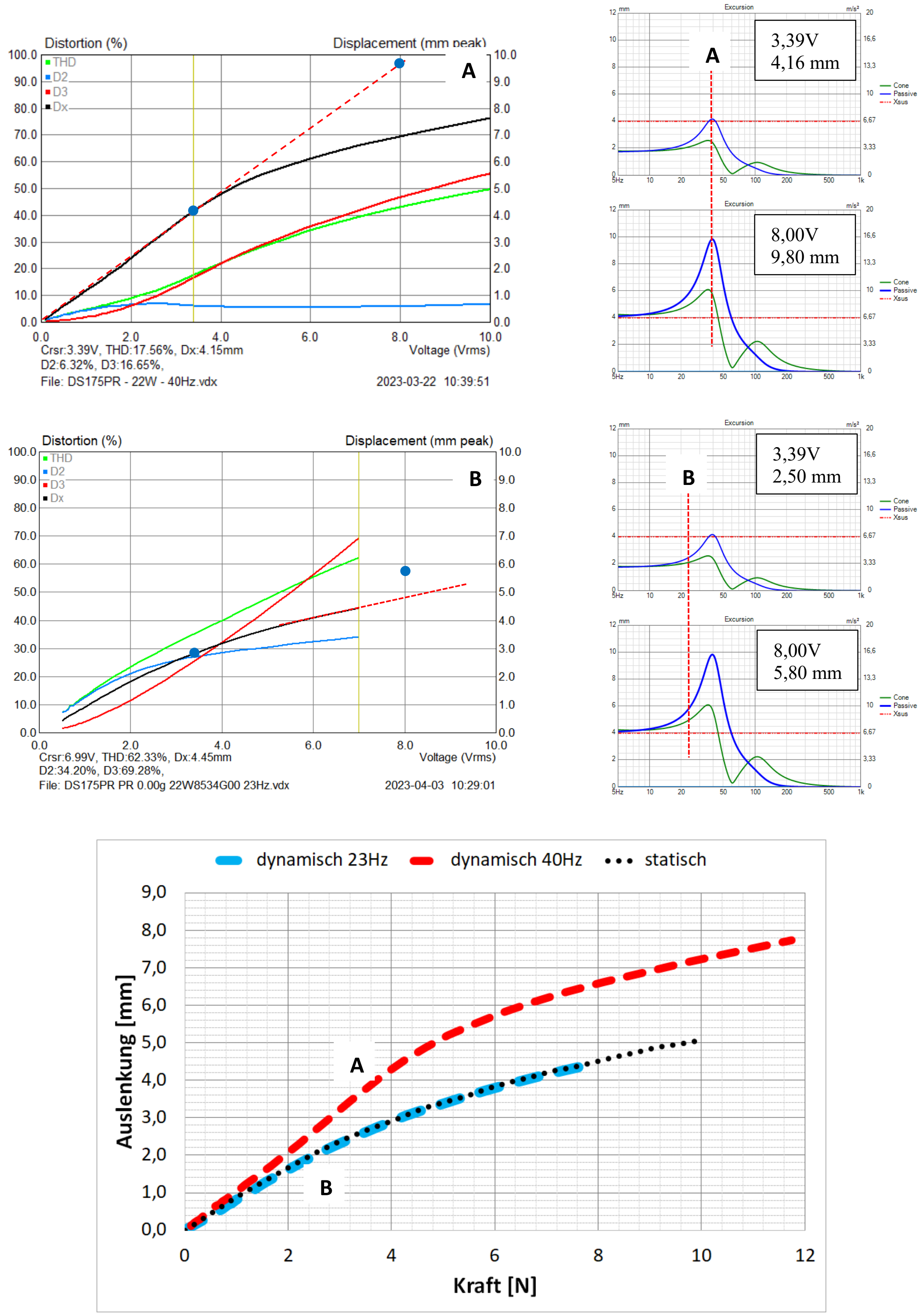
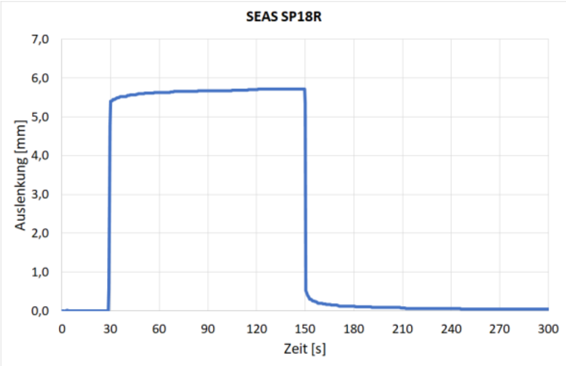


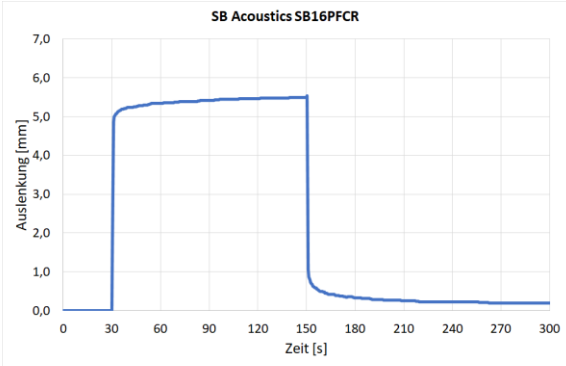
Figure 23: Determination of the linear excursion

A NNEX 4

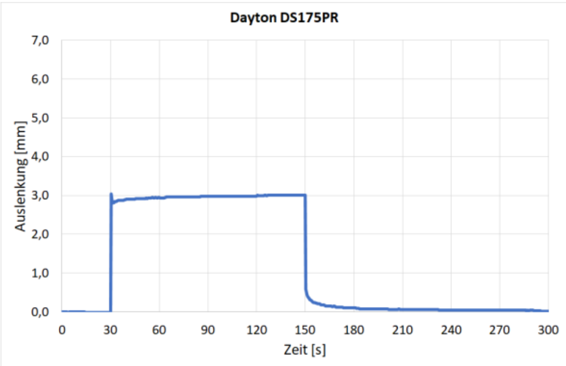
Results of the creep tests



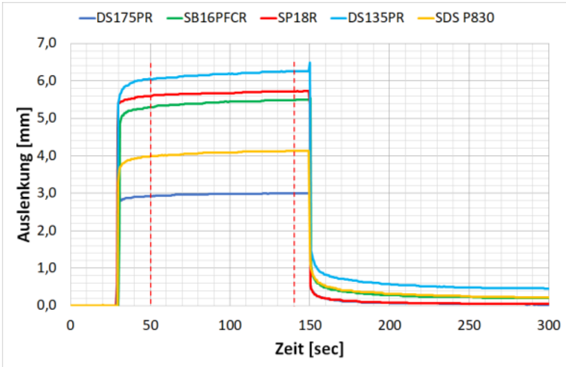
SP18R, Cmp = 1,22-1,25mm/N (2,02mm/N)



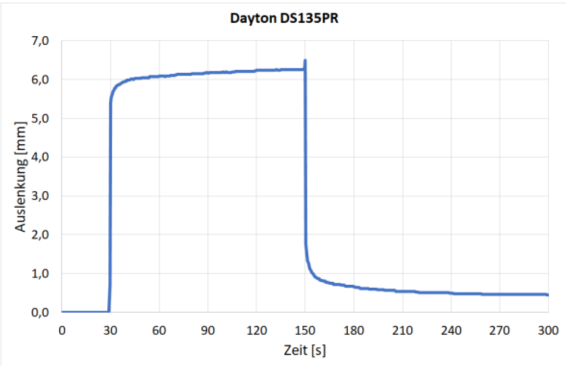
SB16PFCR, Cmp = 1,16-1,20mm/N (1,4mm/N)



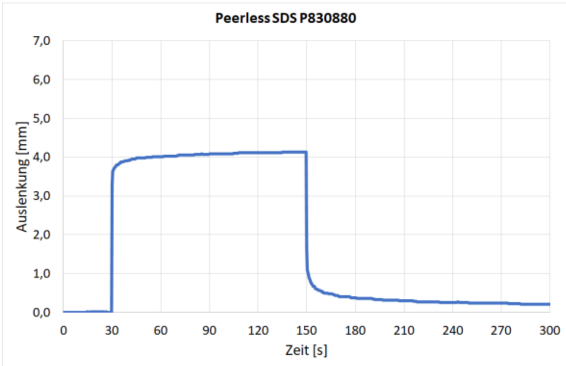
DS175PR, Cmp = 0,64-0,66mm/N (0,45mm/N)



Summary



DS135PR, Cmp = 1,32-1,37mm/N (1,52mm/N)



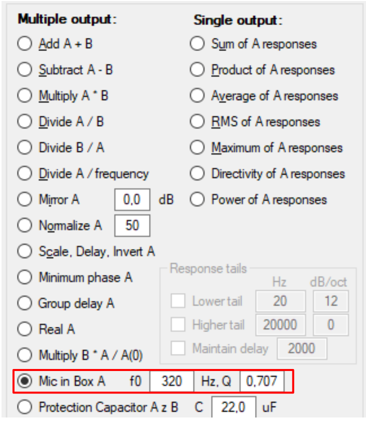
SDS P830880, Cmp = 0,87-0,90mm/N (0,72mm/N)

Note 1: *All tests were performed under identical conditions*
Note 2: *Values in brackets are manufacturer's specifications*

Figure 24: Creep tests with F = constant = 4,57 N, T_{load} = 120 sec

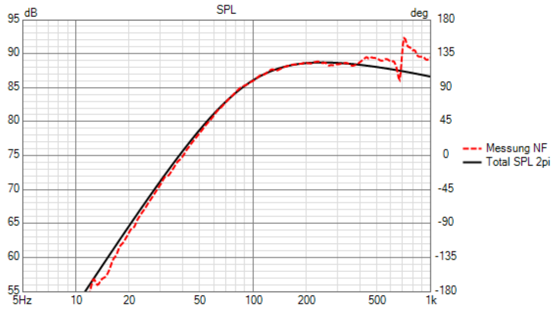
ANNEX 5

As shown in Section 2, MicInBox measurements are required to determine the PM parameters. There is still a useful secondary use for this. Small describes in [09] carrying out a "microphone in the box measurement" to determine the 2π frequency response. This offers the advantage that the frequency response of bass reflex boxes can be determined with **one** MicInBox measurement. D'Appolito explains this technique in detail [10].

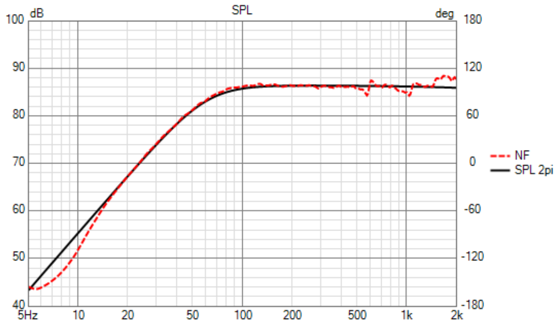


In VCAD, an implementation of the MicInBox technology can be found in the "*Calculator tool*" (see Figure on the left). To do this, the MicInBox measurement is simply imported as frd or txt and converted by activating "*MicInBox A" (see red marking, left).* The set default values usually fit well.

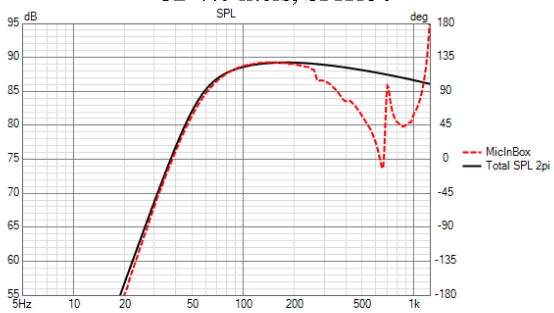
Some measurement results are shown below (red) and compared with the simulation (grey). The agreement is surprisingly good up to about 200 Hz.



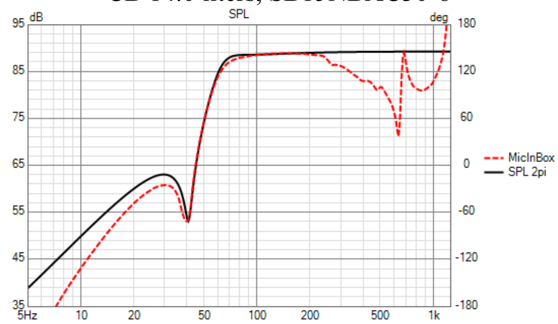
CB 7.0 liters, SPH130



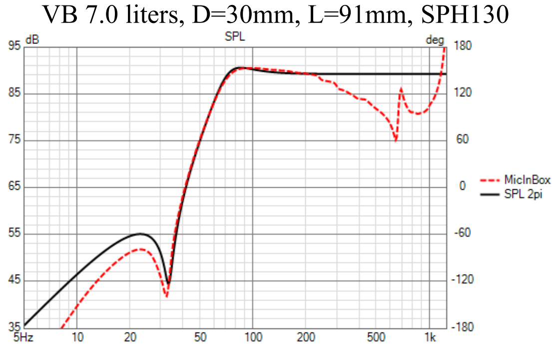
CB 14.0 liters, SB15NBAC30-8



VB 7.0 liters, D=30mm, L=91mm, SPH130



PR 7.0 liters, SPH130 – DS175PR, MA = 0.00g



PR 7.0 liters, SPH130 – SP18R, MA = 0.00g

PR 7.0 liters, SPH130 – SP18R, MA = 19.05g

Figure 25: MicInBox measurements: Comparison of simulation and measurement