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Technical note

Measuring Thiele/Small parameters

A lot can be said about how to measure loudspeaker Thiele/Small parameters. There are different methods of measurement and they are not all equally good (this will not be discussed here). Due to drive unit non-linearities, there is not one final set of parameters for any drive unit. Several of the parameters are a function of cone/voice coil excursion, hence they depend on the input voltage/current level. At SB Acoustics we use the delta mass method (as opposed to delta compliance). We use a constant voltage source and a 150 Ω resistor in series with the drive unit. Hence, this is neither a constant voltage nor a constant current measurement (the value of the resistor is not nearly large enough to approximate constant current, which is not the intention either).

Prior to measuring T/S parameters, the drive unit should be broken in – for two reasons. If the suspension of the drive unit is not broken in, its compliance will slightly increase during the measurement, thus affecting/distorting the results. Furthermore, eventually the drive unit will end up being broken in (it actually does not take that long), which is why it is recommended to use T/S parameters that apply for a broken-in drive unit when calculating box volumes and tuning frequencies. The free air resonance frequency typically drops about 10-15% during break-in, as the suspension compliance increases. This directly affects the Q-factors and the equivalent volume.

To break in a drive unit, you are going to need a sine wave or a noise generator with adjustable output voltage (the former is recommendable) and a power amplifier. Using a sine wave generator, adjust the frequency somewhere below the expected free air resonance frequency of the drive unit (typically about 80% of this value). Slowly turn up the voltage until the suspension reaches maximum displacement. Keep it below clipping level. Usually you can hear when the suspension goes into clipping mode - there will be some kind of mechanical noise. Adjust the voltage slightly below this level. During the process of breaking in the drive unit, it might be necessary to turn down the voltage a little to keep it from clipping, as the suspension softens. It needs to run for about ten minutes. Before measuring, let the drive unit cool to ambient temperature.
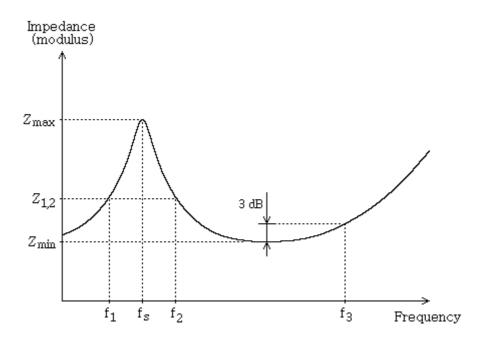
You are now ready to measure the T/S parameters. First measure the voice coil DC-resistance, R_e. It is recommended to use a 4-wire ohm-meter (which is quite expensive), in which case the lead wire resistance is eliminated. You can also use a really good multimeter, but be advised that many low- and mid-priced multimeters will not do the job very well. It needs to have a low resistance range (like 0-20 Ω). It is advisable not to use the lead wires that come with the multimeter when using the lower range, as the quality of these wires is often too poor. Accuracy should be better than ±0.1 Ω, which requires offset correction. Resistance is dependent on temperature. A copper voice coil that measures 6.2 Ω at 25 ℃ will only measure 6.07 Ω at 20 ℃. SB Acoustics specifies voice coil DC-resistance at 25 ℃ and our tolerance is ±0.15 Ω or ±2% (larger value applies).

In order to avoid unwanted mechanical resonances that may affect the results, the drive unit should be held firmly in free air in a vertical position.

Make sure not to seal any vent in the pole piece. Therefore, do not place the drive unit on the floor (which would also make it resonate at some frequency). Furthermore, the drive unit should not be placed near a reflective surface, such as a wall, as this will change the radiation impedance – and we want this to be a free air measurement.

The next step is to measure the impedance curve (i.e. modulus of the impedance). To do this, you need some kind of measurement system. At SB Acoustics we use a stepped sine sweep with narrow frequency spacing (at least 1/24 oct. is recommended). High frequency resolution is crucial in order to be able to accurately determine the free air resonance frequency and the maximum impedance at this frequency – especially with high-Q_{ms} drive units. If it looks like the top of the impedance peak has been chopped off, you need more measurement points. The voltage that should be applied to the terminals of the drive unit depends on its size/type. For a typical mid-woofer, the voltage should be about 1 V (rms) at the resonance frequency.

Notice, only SI-units are used in the following equations. Results may be converted into other units afterwards.

Determine the free air resonance frequency, f_s [Hz].

Determine the maximum impedance level (at the free air resonance frequency), Z_{max} [Ω].

Calculate the impedance level, $Z_{1,2}$ [Ω], at the side frequencies.

$$Z_{1,2} = \sqrt{R_e \cdot Z_{max}}$$

Determine the side frequencies (these are not the quadrant frequencies!), f_1 and f_2 [Hz].

Verify:

$$\sqrt{f_1 \cdot f_2} = f_s$$

Deviation from the measured value indicates drive unit non-linearities (or an inaccurate measurement).

Calculate the mechanical Q-factor, Q_{ms}.

$$Q_{ms} = \frac{f_s}{f_2 - f_1} \cdot \sqrt{R_0}$$

, where

$$R_0 = \frac{Z_{max}}{R_e}$$

Calculate the electrical Q-factor, Q_{es}.

$$Q_{es} = \frac{Q_{ms}}{R_0 - 1}$$

Calculate the total Q-factor, Q_{ts}.

$$Q_{ts} = \frac{Q_{ms} \cdot Q_{es}}{Q_{ms} + Q_{es}}$$

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Now attach an accurately weighed amount of sticky material (e.g. plasticine), *Δm* [kg], to the centre part of the cone or to the dust cap (be careful not to damage the dust cap). Do not be tempted to use small magnets on either side of the cone as added mass, as this will affect the measurement results. Add about 70% of the expected moving mass of the drive unit. Make sure that the entire added mass sticks to the cone, so that no part of it can vibrate freely. Notice that removal of sticky material may cause certain types of paper cones to delaminate in the top layers.

Once again measure the impedance curve - do not adjust the voltage (or current).

Determine the new/shifted resonance frequency, *f₀* [Hz].

Calculate the moving mass (incl. air), *m_ms* [kg].

$$m_{ms} = \frac{\Delta m}{\left(\dfrac{f_s}{f_o}\right)^2 - 1}$$

Calculate the mechanical (loss) resistance, *R_ms* [kg/s].

$$R_{ms} = \frac{2 \cdot \pi \cdot f_s \cdot m_{ms}}{Q_{ms}}$$
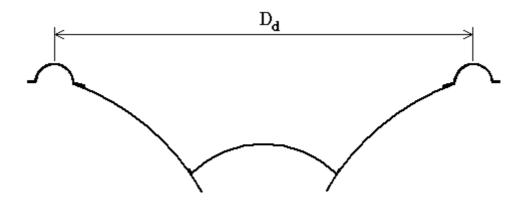
Calculate the force factor, *BL* [Tm].

$$BL = \sqrt{(Z_{max} - R_e) \cdot R_{ms}}$$

Calculate the compliance of the suspension, *C_ms* [m/N].

$$C_{ms} = \frac{1}{(2 \cdot \pi \cdot f_s)^2 \cdot m_{ms}}$$

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Measure the piston diameter (as shown in the figure below), D_d [m].

Calculate the piston area, S_d [m^2].

$$S_d = \pi \cdot \left(\frac{D_d}{2} \right)^2$$

The effective piston area is approximately 95% of the above calculated value in most cases. Hence, a correction should be made. A correction must also be made if the drive unit uses a porous/vented dust cap or a phase plug, obviously.

Calculate the equivalent volume, V_{as} [m^3].

$$V_{as} = C_{ms} \cdot \rho \cdot c^2 \cdot S_d^2$$

ρ is the density of air, ρ = 1.2 kg/m^3 (20 °C, 50% RH, 1 atm)
c is the speed of sound in air, c = 344 m/s (20 °C, 50% RH)

Determine the minimum impedance level above the resonance frequency, Z_{min} [Ω].

Determine the frequency, f_3 [Hz], at which the impedance level is 3 dB above Z_{min} (3 dB is a factor of √2).

Calculate the voice coil inductance, L_e [H]. An empirical equation is used, as a voice coil sitting in a motor system does not behave like a true inductor. This model for voice coil inductance is rather simple – better lumped models have been made.

$$L_e = \frac{\left(\dfrac{R_e \cdot 20 \cdot 10^3}{2 \cdot \pi \cdot f_3} + 0.5 \right) \cdot 10^{-3}}{20}$$

You now have a complete set of Thiele/Small parameters.