Bass tuning using the Thiele and Small parameters

Dr. Peter Strassacker
Loudspeaker design since 1977
Books on material research and field theory
Design of loudspeakers like Lagrange 98, Pascal,Nova 2, Nova 3, Sub 12, Sub 22, Sub 30

Peter Strassacker interviewed by
Frank Kleiber on Thiele & Small parameters (7/2004).

Frank:
Peter, what's the purpose of Thiele and Small parameters?

Peter:
When I started designing loudspeakers in the 70's bass tuning was done by trial-and-error. Lots of cabinets had to be built and many bass drivers had to be examined. This was time-consuming and expensive. The frequency response mentioned in the manufacturer's data sheets didn't help since the bass depends on the cabinet used. Then A.N. Thiele and Richard H. Small (T&S) came up with a calculation system that can be used to calculate the frequency response of the bass.

Frank:
What's needed to do this?

Peter:
Only with the data (T&S parameters) for:
- driver free air resonance Fs
- equivalent volume of compliance Vas
- total Q factor Q_{ts} (consisting of Q_{es} and Q_{ms})

the bass may be calculated (refer to calculator for closed cabinets and bass reflex cabinets).

Frank:
How can we determine these parameters?

Peter:
Either by looking it up in the driver's data sheet or by impedance measuring on the driver.

Frank:
Peter, what do these parameters mean?

Peter:
The most important parameters are:

The resonance frequency Fs (Frequency speaker)
This parameter is the free air resonance frequency of the driver. In other words: it's the frequency that the driver likes to resonate with. This frequency is determined by the diaphragm's and voice coil's weight and the reset force (of diaphragm surround and spider).

Equivalent volume of compliance Vas (Volume acoustic speaker)
Vas is an artificial measurement for the reset force of the diaphragm suspension (diaphragm surround and spider). It's a theoretical air volume (compressed behind the diaphragm) that pushes the diaphragm back as much as the suspension does. A high value indicates a high air volume that is hardly compressed and therefore doesn't push back that much; a smaller value indicates a stiff suspension.

Total Q factor Qts (quality total speaker)
Qts is the total quality factor of the driver. It's calculated from Qms and Qes: Qts = (Qms*Qes)/(Qms+Qes).

Mechanical Q factor Qms (quality mechanical speaker)
Qms is a measurement for the mechanical Q factor of a driver. It's dependent on the loss of the mechanical suspension (diaphragm surround and spider). This value should be as high as possible.

Electrical Q factor Qes (quality electrical speaker)
Qes is a measurement for the electrical Q factor. It's equivalent with the strength of the drive: the smaller the value the stronger the drive, usually comprising voice coil and magnet.

Frank:
Is there a rule of thumb telling us which driver is suited for which cabinet?

Peter:
Yes, there is; below is a small table:

Qts value	Description	Suitable for
0.2-0.4	very strong drive	horn speakers
0.3-0.5	strong drive	bass reflex speakers, horns
0.4-0.6	medium drive	closed cabinet speakers
0.5-0.7	weak drive	transmission line speakers, dipoles
> 0.7	very weak drive	dipoles, automotive: rear parcel-shelf

Frank:
Peter, are there any more important parameters?

Peter:
Yes, there other parameters that are often used:

The DC resistance Re (sometime called RDC)
Contrary to the impedance, equivalent to AC resistance, that changes over the frequency range (it's very high at the resonance frequency), the DC resistance is fixed. This value is approximately 30% lower than the rated impedance and indicates the resistance for DC. This resistance is caused by the ohmic resistance of the voice coil. It's measured in Ohm.

The voice coil inductance Le
Like any other coil, the voice coil possesses an inductance. This inductance causes a rising impedance with increasing frequency. The inductance is measured in milli henry (mH).

The electromagnetic force factor BxL or BL
Expressed either in tesla metre or power / current (N/A). This factor indicates which force is applied to a locked diaphragm at current of 1 ampere. The higher the value the stronger the drive and the better controlled is the diaphragm by the drive.

Diaphragm mass Mmd
This is the mass of all moving parts: diaphragm, surround, spider, dust cap, voice coil.

Effective mechanical mass including sir load Mms (Mass mechanic speaker)
This parameter indicates the moving mass Mmd of the driver plus the air load on the diaphragm (has to be moved too).

Maximum peak linear excursion Xmax
Xmax is the measurement for the maximum linear excursion of the voice coil and is expressed in mm. It's the distance the voice coil travels without leaving the magnet field. Xmax = ½ (voice coil height - pole piece thickness)

Effective piston radiating area Sd
This parameter indicates the effective diaphragm area in cm².

Sensitivity SPL
The sensitivity indicates the maximum volume of a loudspeaker. The standard measurements are:
- dB/W/m, i.e. the maximum volume at one Watt input measured in one metre distance
- dB/2.83V/m, i.e. the maximum volume at 2.83 Volt (at 8 Ohm impedance this is exactly 1 Watt)

Frank:
Peter, is it possible to calculate the tuning yourself using these parameters?

Peter:
Sure, here are the formulas:

Closed cabinet speaker:
Required T&S parameters
fs = resonance frequency of the driver

Bass reflex speaker:
Required T&S parameters
Fs = resonance frequency of the driver

Vas = equivalent volume of compliance
Qts = total Q factor of the bass driver
Qtc = the systems Q factor

Calculation of the cabinet volume Vb:

Vb = Vas / ((Qtc²/Qts²) - 1)
whereby the resonance frequency fc of the closed cabinet:
fc = Qtc * fs / Qts

Which system Q factors Qtc do make sense for a closed cabinet speaker:
- Qtc = 0.5 suitable for high-end, almost no low bass
- Qtc = 0.577 (Bessel characteristics) with ideal phase response, but with less low bass
- Qtc = 0.7-0.9 for all-round applications, whereby Qtc=0.707 (Butterworth) is often regarded as ideal
- Qtc > 0.9 ??? for maximum low bass in a closed cabinet, sounds sometimes a bit boomy.

Fc = system resonance
Fb = cabinet resonance
Qts = total Q factor of the bass driver
Qtc = the systems Q factor
A = bass reflex port area
Vb = net volume of the cabinet
Vas = equivalent volume of compliance
Fc = Fs * [square root (Vas / Vb)] +1
Qtc = Qts * [square root (Vas / Vb)] +1
If Qtc < 0,7 then take factor 0.75 for calculating Fb.
If Qtc > 0.7 then take factor 0.60 for calculating Fb.
This results in:
Fb = 0.6 * Fc or
Fb = 0.75 * Fc
The length of the bass reflex tube is calculated dependent on the port area size.
l = [(1176490 * A) / (39.4784 * Fb² * Vb)] - (0.5 * [square root (pi * A)])
A for varied tube diameters:
70mm = 38.5cm²
100mm = 78.5cm²
150mm = 176.8cm²
A may be substituted by the area of a self-built reflex tube port. Calculation of bass reflex cabinets with a calculator, abbreviations & TSP´s :
Fs = resonance frequency of the driver
Qts = total Q factor of the bass driver
Vas = equivalent volume of compliance
SD = effective piston radiating area of driver
AF = port area size of the reflex tube (circular)
X = diameter
Calculation of the minimum port area size(reflex tube):
AF > 0.1 x SD
X is calculated from AF:
X = (square root AF): 3.14 x 2
Volume calculation (Vb) of the bass reflex cabinet (net):
Vb = 15 x Vas x Qts²,87
Reflex tube length (l) calculation:
l = [(168939 x AF x Qts)²: (Fs² x Vb)] - [0.88x (square root AF)]