Measuring Thiele / Small Loudspeaker Parameters

Prior to 1970, there were no easy or affordable methods accepted as standard in the industry for obtaining comparative data about loudspeaker performance. Recognized laboratory tests were expensive and unrealistic for the thousands of individuals needing performance information. Standard measurement criteria were required to enable manufacturers to publish consistent data for customers to make comparisons between various loudspeakers.

In the early seventies, several technical papers were presented to the AES (Audio Engineering Society) that resulted in the development of what we know today as 'Thiele-Small Parameters'. These papers were authored by A.N.Thiele and Richard H. Small. Thiele was the senior engineer of design and development for the Australian Broadcasting Commission and was responsible at the time for the Federal Engineering Laboratory, as well as for analyzing the design of equipment and systems for sound and vision broadcasting. Small was, at the time, a Commonwealth Post-graduate Research Student in the School of Electrical Engineering at the University of Sydney.

Thiele and Small devoted considerable effort to show how the following parameters define the relationship between a speaker and a particular enclosure. However, they can be invaluable in making choices because they tell you far more about the transducer's real performance than the basic benchmarks of size, maximum power rating or average sensitivity. There are several different ways to measure the Thiele/Small parameters of a loudspeaker driver. The method described here provides a way for the beginner and DIY enthusiast to measure the parameters without any expensive or specialised equipment.

Definitions:

Re	:	Electrical resistance of voice coil
Fs	:	Resonant frequency of loudspeaker moving mass (in free air)
Qes	:	Electrical Q of loudspeaker
Qms	:	Mechanical Q of loudspeaker
Qts	:	Total Q of loudspeaker
Vas	:	Equivalent air volume of moving mass suspension

Measuring Re, Fs, Qes, Qms and Qts

To measure these parameters using the method outlined below, you'll need to have the following items:

- A power amplifier rated at 10 Watts (RMS) or more.
- Audio frequency oscillator.
- Digital multimeter (with frequency measurement).
- A 5 watt resistor (any value between 4 to 10 ohms).
- Alligator clip leads - you will need 4 sets of leads (leads may be soldered instead if desired)

Figure 1 shows a typical impedance curve for a loudspeaker (see Figure 5 for the equivalent circuit of this "speaker", which was simulated for this article). Resonance causes a large increase in impedance, and at some higher frequency, the inductance of the voice coil causes the impedance to rise again. The region for the initial measurements must be within the "linear" region of the impedance curve. In the example below, resonance is at 27Hz, and the linear region ranges from about 100Hz to 400Hz.

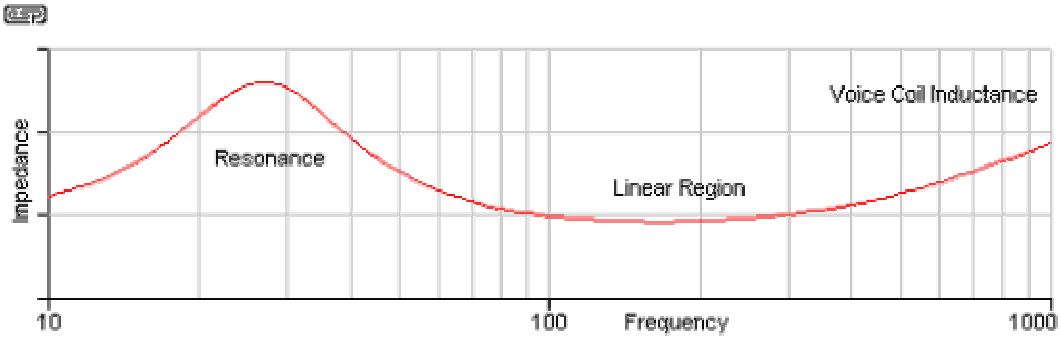

Figure 1 - Loudspeaker Impedance Curve

At resonance, the speaker impedance is pure resistance. As the frequency increases towards resonance, the impedance characteristic is inductive. Beyond resonance as impedance falls, the impedance characteristic is capacitive. Within the "linear" region, the impedance is again (almost) resistive, but at the speaker's nominal impedance. At the frequency where the inductance of the voice coil becomes significant, impedance is progressively more inductive as the frequency rises. It is common to add a compensation network to maintain an overall resistive characteristic at these higher frequencies, so that the performance of the crossover network is not compromised. This is not necessary with an active crossover.

The multimeter should be capable of measuring frequency, as well as AC voltage and resistance. If it cannot, a frequency counter is highly recommended, since the frequency measurements are critical. The amplifier must be capable of reproducing from 10 Hz to 2 kHz with no variation in output voltage. It is imperative that it is insensitive to any load above 4 ohms. The audio oscillator must also produce a signal with relatively low distortion, and the output voltage must not vary as the frequency is adjusted.

- Measure the resistance across the speaker terminals to obtain **Re**.
- Measure the exact resistance of the 5 Watt source resistor, **Rs**.

The loudspeaker driver should be suspended in free space, with no obstructions or interfering surfaces nearby. Any boundary closer than around 600mm (about 2ft) will affect the accuracy of the measurements

Connect the circuit as shown in Figure 2, with the audio oscillator to the input terminals of the amplifier, but with the multimeter across the amplifier output terminals instead of the resistor.

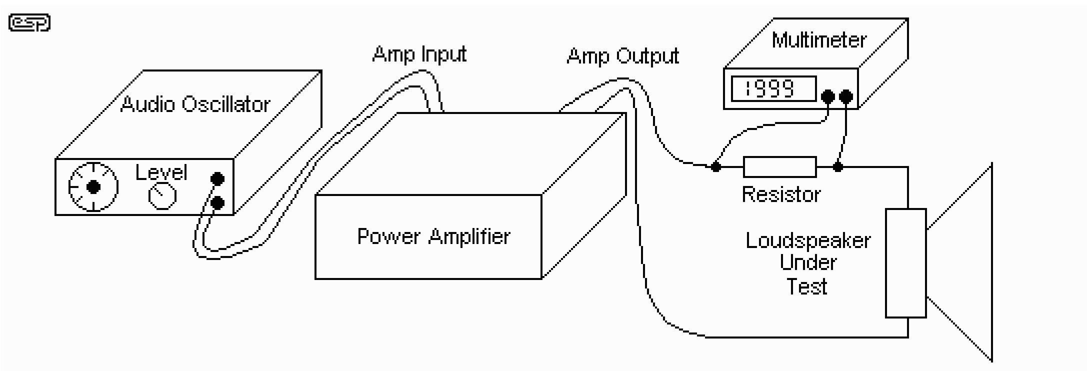

Figure 2 - Measuring the Main Speaker Parameters

Set the oscillator to approximately 100 to 200 Hz (or at least 2 octaves above resonance).

Set the output of the amplifier to between 0.5V and 1.0V (this is **Vs**). You may need to experiment with different voltages, depending on the accuracy of your current readings (or calculations). Do not be tempted to use higher voltages, as the speaker may be driven outside its linear range, which ruins the validity of the measurements. The parameters being measured are "small signal", and it essential that a small signal is actually used.

Calculate the speaker current (**Is**), to make sure that you will have a reasonable current to work with. Check that the speaker is nowhere near resonance, by changing the oscillator frequency by 50Hz or so in either direction and measure the voltage across the speaker. It should not change by any appreciable amount.

$$Is = \frac{Vs}{(\mathrm{Re} + Rs)}$$

Re-connect the circuit as shown in Figure 2, again using the alligator clip leads where necessary.

Adjust the frequency until the voltage across the resistor reaches a null (minimum level). Without changing anything, carefully measure the frequency and voltage across the resistor...

Frequency	:	Fs
Voltage across the resistor	:	Vm

Calculate the following...

Speaker current	:	$\mathrm{Im} = \frac{Vm}{Rs}$
Driver impedance at resonance	:	$Rm = \frac{(Vs - Vm)}{\mathrm{Im}}$
r0	:	$r0 = \frac{Is}{\mathrm{Im}}$
-3dB Current	:	$Ir = (\mathrm{Im} * Is)^{0.5}$
-3dB Voltage	:	$Vr = Ir * Rs$

Complete the measurements for **Fl** and **Fh**, for which the voltage across the source resistor is equal to **Vr**, and as a sanity check (to ensure that your calculations and measurements are accurate), calculate the resonant frequency based on these last two measurements.

Check that..	:	$\sqrt{(Fl * Fh)} = Fs$

If the above checks out (within 1 or 2Hz), then **Qes**, **Qms** and **Qts** can be calculated as follows:

Qms	:	$Qms = Fs * \sqrt{\frac{r0}{(Fh - Fl)}}$
Qes	:	$Qes = \left(\frac{Qms}{(r0 - 1)}\right) * \left(\frac{\mathrm{Re}}{(Rs + \mathrm{Re})}\right)$
Qts	:	$Qts = Qms * \frac{Qes}{(Qms + Qes)}$

Measuring Vas (equivalent air compliance)

To measure Vas, use a good solid enclosure of known volume that is approximately a cube of the nominal speaker size. For example, a 300mm driver (12") needs a box of about 28 litres (1 cu ft). For reference, a cubic foot is 28.3168 litres, and one litre is contained by a cube of 100mm to each side.

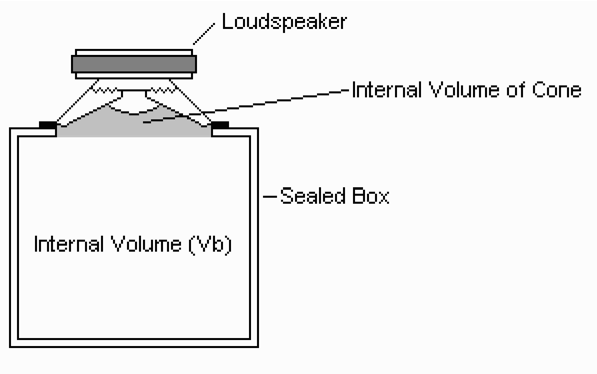

Figure 3 - Setup for Measuring Vas

Determine the total volume, including the speaker cut-out and that trapped by the cone with the speaker mounted on the outside of the box for easy access. Measure the resonant frequency in this situation, and use the free air space resonant frequency determined as shown above. Determining the volume trapped by the speaker cone is slightly tricky.

Use one of the following methods...

- Place the driver in a plastic bag, ensuring it is completely sealed. The bag should be loose enough so that it can be pushed easily into the cone area. Place the wrapped speaker on a flat surface, with the cone facing upwards. The cone may now safely be filled with water, and the water carefully poured out into a measuring jug. The resulting measurement will be a little greater than the actual volume because the cone will be depressed by the mass of the water. The area of the speaker cut-out in the cabinet must still be added. A suggestion was made on the Guestbook by "Chuck" that rice would be a better alternative, as there is less chance of a disaster. Good idea, and strongly recommended. The bag is still worthwhile, as it will prevent small particles from entering the voice coil gap (especially important for drivers with phase plugs, as they are not sealed).
- Take a series of measurements. The internal cone area is measured, then divided into sections whose volume may be calculated. For most speakers we will have two basic shapes to deal with, and although this method is not 100% accurate, it will probably give the best result in the majority of cases.

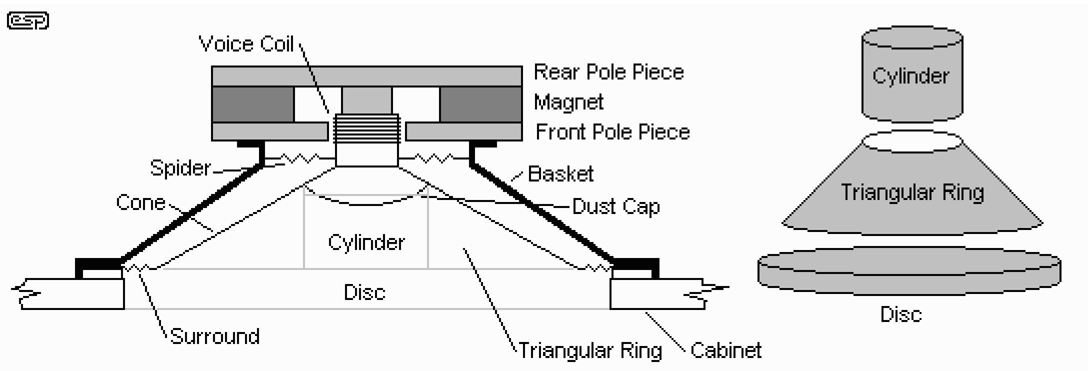

Figure 4 - Determining the Volume of the Cone

There is a flat cylinder (disc) that is formed by the outer area of the basket and the cutout in the enclosure. The triangular ring is formed by the cone itself, as shown above. Finally, the cylinder occupies the area over the dust cap. The depth of the cylinder should be an approximate average of the distance from the mounting surface and the dust cap.

The volume of cylinder and disc is given by the conventional formula...

$V_{cyl} = \pi * r^2 * h$ (Where r is the radius and h is height) and...

$$V_{disc} = \pi * r^2 * h$$

The triangular ring's volume is given by...

$$V_{ring} = \frac{((\pi * r^2 * h) - V_{cyl})}{2}$$

The total speaker volume is simply the sum of the 3 volumes calculated above. Box volume is calculated as one normally would, take great care to ensure that the measurements are accurate. The box may be braced, but must have no fibreglass or other sound deadening material inside. Make sure that the volume occupied by any bracing is accounted for in your calculations. Even a simple box will be sufficiently rigid at the frequencies of interest, so a completely acoustically dead cabinet is not required (although it won't hurt). Do **not** use any speaker cabinet filling material for this test.

$$Vas = Vb * \left(\left(\frac{Fb}{Fs} \right)^2 - 1 \right)$$

Where **Vb** is the volume trapped by the speaker and box, and **Fb** is the resonance frequency of speaker and box combined. **Fs** is the free air resonance measured previously.

An Example Calculation

A "dummy" or test loudspeaker was described in another contributed article, and I have used a simulation of a similar speaker in the calculations shown. The equivalent circuit of the speaker is shown in Figure 5. This circuit was also used to create the impedance graph shown in Figure 1.

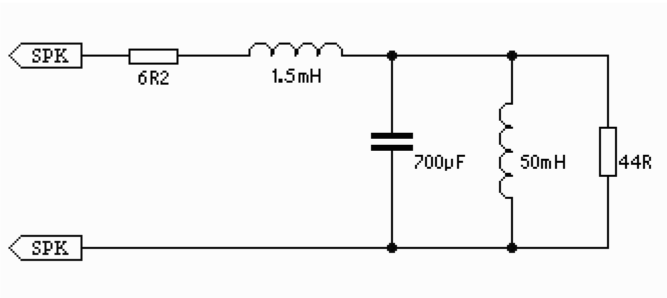

Figure 5 - Dummy Test Loudspeaker

The following screen shot shows the values for the "speaker", and the only contrived (i.e. invented) value is for the resonance in the sealed box. It was necessary to invent a number here, as it is not possible to simulate it. The final figure shown is fairly typical of many such drivers, so is not too far from the truth either.