LIMP - MANUAL

Impedance Measurement
Thiele Small Parameters (TSP)
RLC Meter

Based on the original LIMP Manuals
Original tutorial in German by Dr Heinrich Weber
Original manuals in English prepared by Dr Ivo Mateljan

Translation into English of Version 2.40D (ARTA 1.80)
Christopher J. Dunn, Hamilton, New Zealand, September 2014

Contents

Foreword

Because of the increasing scope and complexity of the ARTA Handbook, the LIMP Manual is now presented separately to those for the other programs in the ARTA family.

LIMP is for impedance measurement and determination of Thiele-Small (TS) parameters. LIMP can also be used as an LCR meter. Available excitation signals include pink noise (PN) and stepped sine.

This handbook has been written to help acquaint users with the LIMP part of the ARTA family of programs. Note however that it is not a substitute for the original user's manual that comes with the software, and the two should be used in parallel with each other.

Further information can be found on the ARTA website, which contains the most up-to-date releases and application notes. Although we aim to continue to supplement and update this handbook in line with the continuing development of the software, we would ask for your patience with any discrepancies that may arise from time to time. Suggestions for improvements and corrections are always welcome.

1. Introduction to LIMP

1.1. Installation requirements

To use the ARTA suite of programs you will need:

- Operating system: Windows 98/ME/2000/XP/VISTA/Windows 7/ Windows 8;
- Processor: Pentium 400MHz or higher, memory 128k;
- Soundcard: full duplex.

Installation is very simple. Copy the files to a directory and unzip them. That's it! All registry entries are automatically saved at first start-up.

1.2. Equipment

The following is a brief summary of the equipment required accompanied by some basic directions and cross-referenced to more detailed information elsewhere.

Soundcards

There are three types of soundcard:

- Standard onboard soundcard, found typically on a computer motherboard;
- Plug-in cards for PCI or ISA bus;
- Soundcards connected via USB or firewire.

Essentially, all three types are suitable for use with LIMP if they have an output channel (Line Out) and two input channels (Line In). Note however that onboard sound cards fitted to laptop computers often have a single (mono) channel only, identified as the microphone input (Mic In).

Amplifier

A power amplifier with linear frequency response and power 5–10 watts is adequate. The output impedance should be <0.05 Ohms. An inexpensive solution that meets these requirements and is small and easily portable is the Thomann t.amp PM40C (see also ARTA Handbook Section 5.4).

ARTA Measuring Box

The ARTA Measuring Box is not absolutely necessary, but it does make life a lot easier. When switching between acoustic and electric measurements, the annoyance of having to swap multiple cables is replaced by the simple flick of a switch (see Application Note 1 (1)).

Multimeter

A multimeter for use with STEPS is not strictly necessary, but it is nevertheless indispensable for the calibration of the measurement equipment to be used. Besides, a good meter is a useful tool for all manner of other measurements. If you do not have a multimeter, you should ideally opt for a 'true RMS' type. There are plenty of options on the market for well below €100.

Cables

Several cables are required, all of which should be of good quality. Poor connections, inadequate shielding, etc. can interfere with measurements (see also ARTA Handbook Section 6.1.1). Keep all cables as short as possible.

1.3. Pin assignment for cables and connectors

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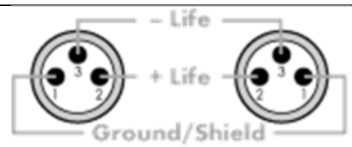
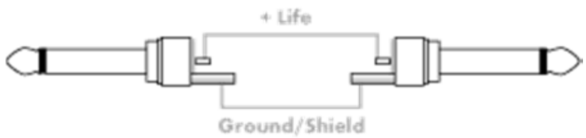
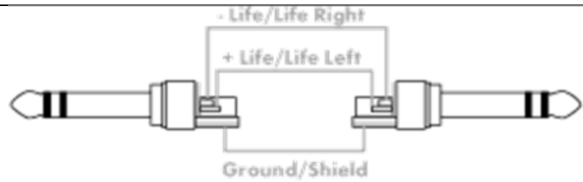
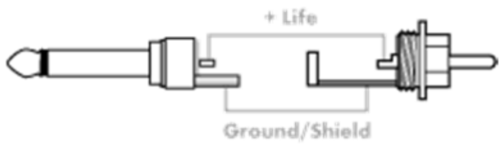
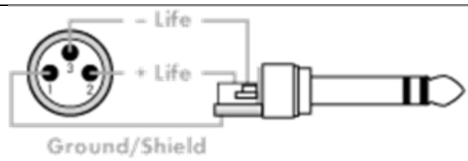
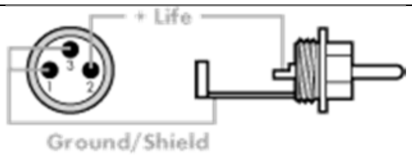
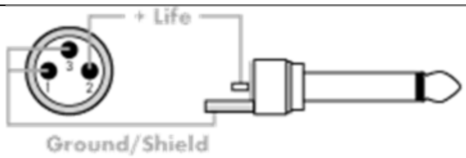
	
	
	
	
	

STEREO JACK	**XLR**
Sleeve: earth (GROUND/SHIELD)	Pin 1: earth (GROUND/ SHIELD)
Tip: +	Pin 2: +
Ring: –	Pin 3: –

Figure 1.3.1 Pin assignment for connecting cables.

2. Measurement principles and setup in LIMP

2.1. Setup

The principles underlying measurement in LIMP are illustrated in Figure 2.1.1.

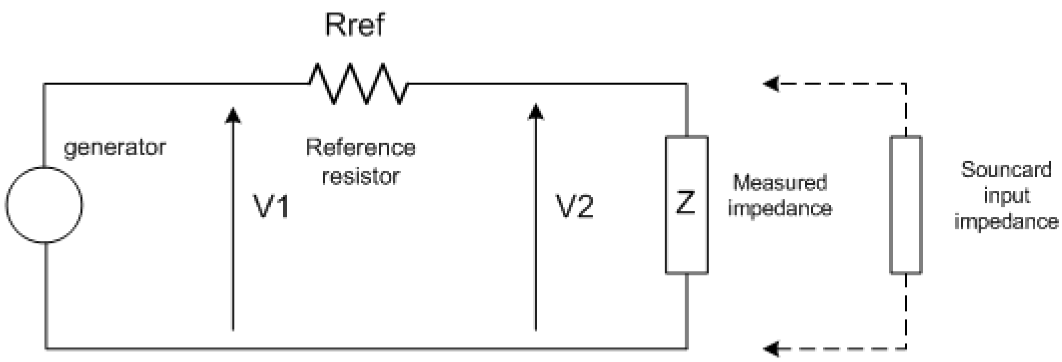


Figure 2.1.1 Impedance measurement circuit.

Voltage V1 (Line in, right channel) through reference resistor Rref and speaker, and V2 (Line in, left channel) via the speaker gives the impedance:

$$Z = Rref \times V2\ (f) \div (V1\ (f) - V2\ (f))$$

In the original LIMP User Manual, reference is made to two test setups:

- Impedance measurement using the headphone jack of the sound card (Figure 2.1.2);
- Impedance measurement with power amplifier (Figure 2.1.6).

2.1.1. Impedance measurement using the soundcard headphone jack

The easiest way to perform an impedance measurement with minimal additional equipment is to use the headphone output of the sound card. All you need is a reference resistor Rref and a small amount of cable.

The measurement setup is shown in Figure 2.1.2. According to the LIMP user manual, the reference resistor Rref should have a value of 100 ohms, but this can vary between 33 and 100 ohms, depending on the sound card.

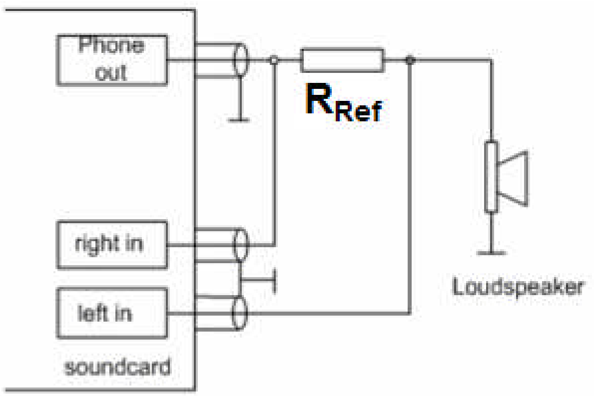


Figure 2.1.2 Impedance measurement using the soundcard headphone output.

The high value of the reference resistor is dictated by the fact that soundcard headphone outputs are usually not designed for connection to speakers. Figure 2.1.3 compares the impedance curves of a standard headphone and a speaker. The much reduced relative impedance of the speaker shows clearly how the headphone output could suddenly be asked to deliver far more power than it was ever designed for!

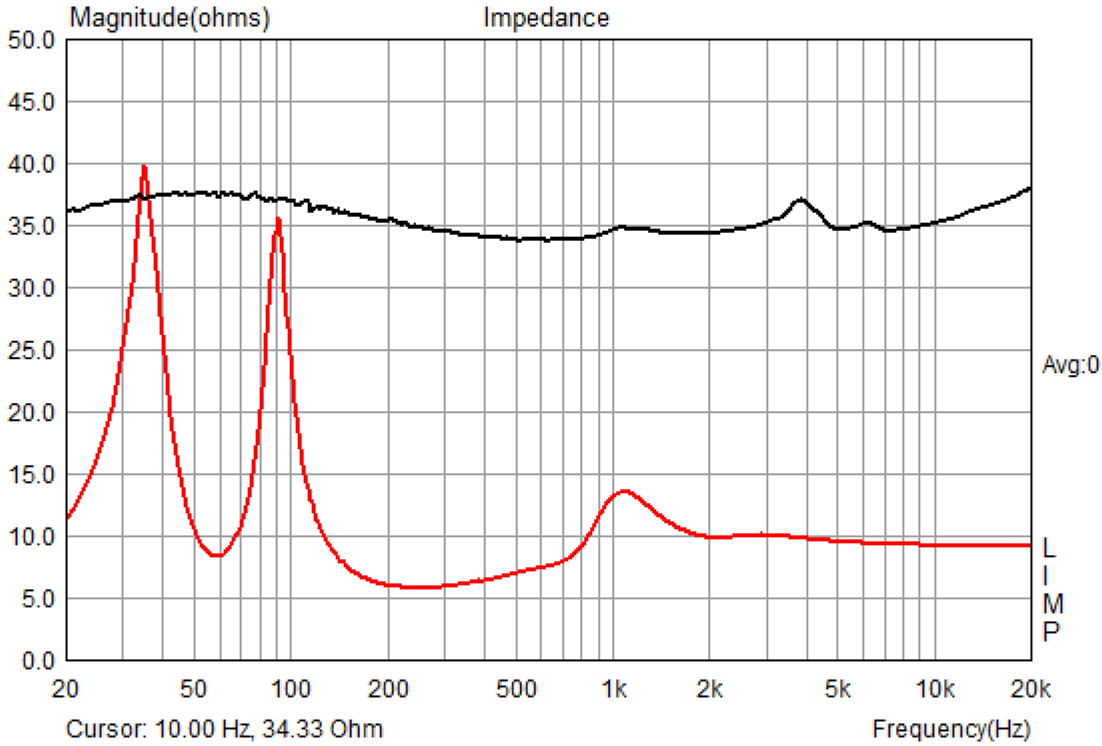


Figure 2.1.3 Typical impedance curves for headphones (black) and a speaker (red).

Figure 2.1.4 shows the specifications for the headphone outputs of two common soundcards.

- The ESI UGM96 delivers a maximum output voltage of +4 dBV = 1.0 * 10^(4.20) = 1.584V;
- The RME Fireface UC provides +19 dBu = 0.775 * 10^(19/20) = 6.907V.

Line- & Kopfhörer-Ausgang

- Type: Stereo 6.3mm Klinkenbuchse
- Max. Ausgangspegel: +4dBV
- THD+N: 0.003% A-gewichtet
- Ausgangsleistung: 100mW Max @ 32 ohm
- Impedanz: 32 ~ 600 ohm

Figure 2.1.4 Soundcard headphone output specs (in German), ESI UGM96 *(Klinkenbuchse = jack; Ausgangspegel = output level; A-gewichtet = A-weighted; Ausgangsleistung = output; Impedanz = impedance).*

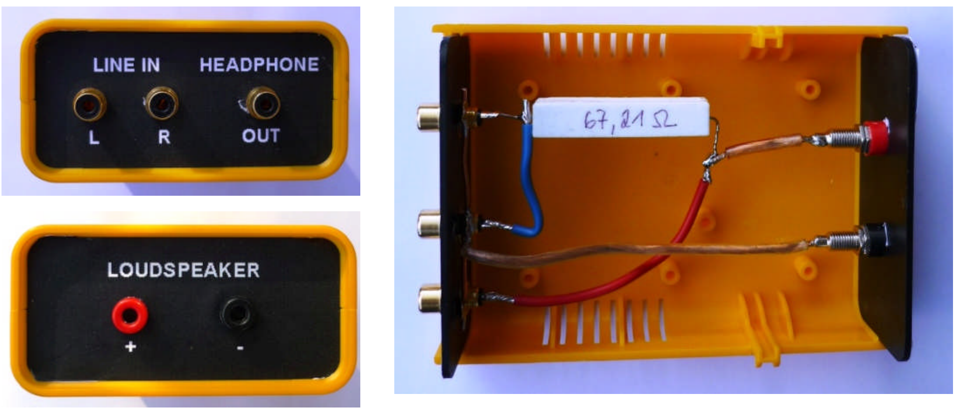


Figure 2.1.5 Practical implementation of Figure 2.1.2.

Figure 2.1.5 shows a practical implementation of the circuit illustrated in Figure 2.1.2. Such a set up is not necessarily essential, but it does help to prevent errors that might result in damage to the soundcard.

2.1.2. Impedance measurement using a power amplifier

Because the headphone output has only a limited current capability, it can be replaced by a power amplifier (although the higher power levels that are needed for acoustic measurements are not necessarily required for impedance measurements). Under this arrangement (Figure 2.1.6), the reference resistor must have a lower impedance. The recommendation from the original LIMP user manual is Rref = 27 ohms.

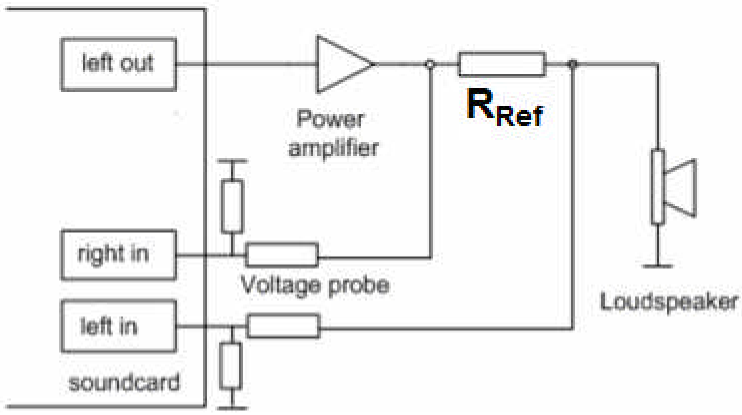


Figure 2.1.6 Impedance measurement using a power amplifier.

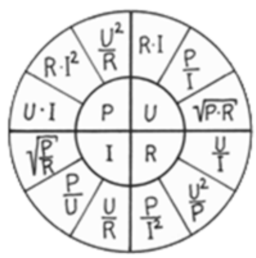
When using a power amplifier, be aware that the output voltage can be significantly higher than the output of the headphone jack. These higher voltages can overload or even damage the soundcard. The use of a voltage divider (voltage probe) is therefore recommended. For example:

```
Hi-Z Instrumenteneingang
 - Type: unsymmetrisch 6.3mm Klinke
 - Max. Eingangspegel: +4.5dBV max
 - THD+N: 0.003% A-gewichtet
 - Impedanz: 500 kOhm
```

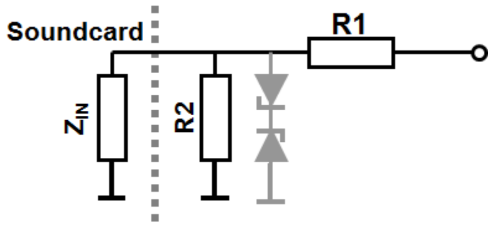
Figure 2.1.7 Soundcard line in specifications, ESI UGM96 (*Instrumenteneingang = input specs; unsymmetrische 6.3mm Klinke = unbalanced 6.3mm jack; Max. Eingangspegel = max. input level; A-gewichtet = A-weighted; Impedanz = impedance*).

- Maximum soundcard input voltage $V_{IN\ MAX}$ = +4.5dBV = 1.0 * 10^(4.5/20) = 1.679V RMS
- Soundcard input impedance Z_{IN} = 500 kOhm
- Amplifier power P = 20 watts.

Using Ohm's law, the maximum output voltage is calculated for a load impedance Z = 8 ohms as follows:



U = SQRT (P * Z)
U = SQRT (20 * 8) = 12.65V
$G_{IN} = V_{IN\ MAX}/V_{OUT\ AMP\ MAX}$ = 1.679/12.65 = 0.1327 = –17.54dB
Thus, a voltage divider giving about 18dB of attenuation is required.



Rx = (Zin * R2) / (Zin + R2) [1]

G = Rx / (R1+ Rx) [2]

R1 = (Rx / G) – Rx [3]

If the input impedance of the sound card Zin = 500 kOhm, and R2 = 10 kOhms, R1 is calculated as follows:

Rx = (500,000 * 10,000) / (500,000 + 10,000) = 9803.92 ohms

R1 = (Rx/G) – Rx = (9803.92 / 0.1327) – 9803.92 = 64076.42 ohms → 68 kOhm

G_{IN} = 9803.92 / (68,000+9802.92) = 0.126 = –17.99dB

Additional hints regarding dimensioning of the voltage divider, see section 6.

The Zener diodes (shown in grey) are not essential but offer additional protection for the soundcard line in. Use them at your discretion.

2.2. Working in LIMP

LIMP has similar top menu commands to the other programs in the ARTA family.

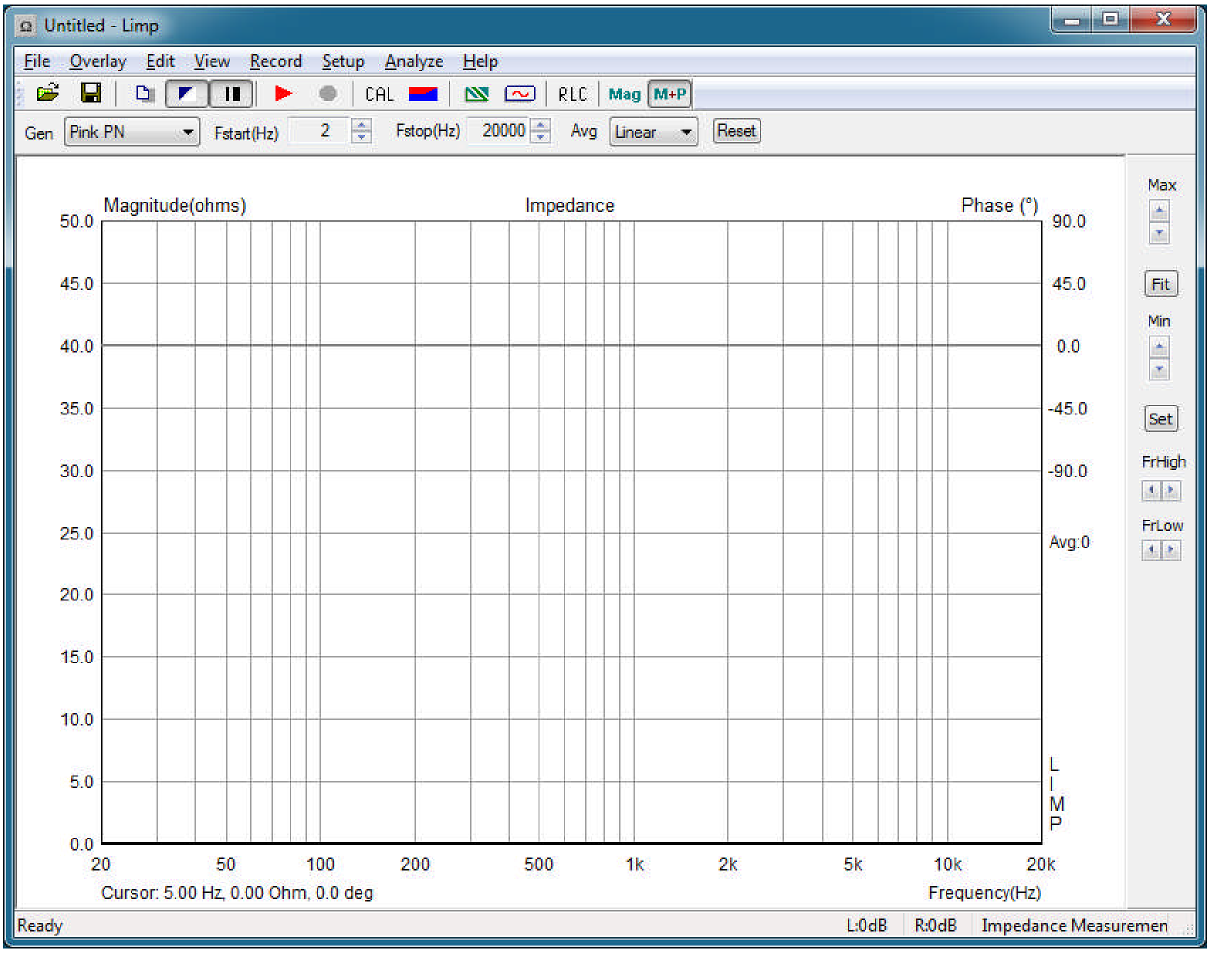


Figure 2.2.1 LIMP opening screen.

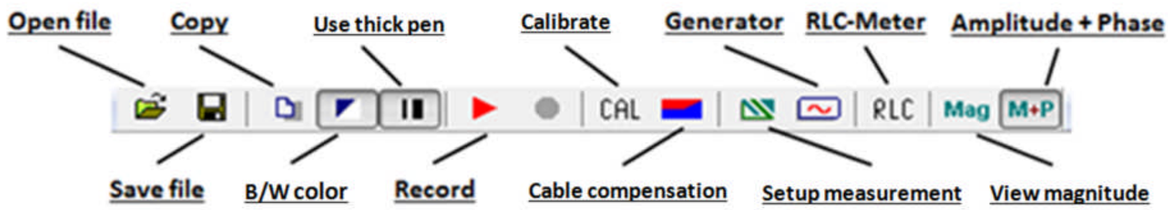


Figure 2.2.2 LIMP toolbar.

2.2.1. Basic settings in LIMP

Before starting, some basic settings have to be entered:

1. Soundcard and input and output channels in 'Soundcard Setup';
2. Measurement parameters in 'Measurement Setup': enter Rref;
3. Soundcard level in 'Generator Setup';
4. System calibration in 'Calibrate Input Channels'.

n.b. Under 'Soundcard Setup' (Figure 2.2.3), you can see whether the soundcard has been detected. Selection of the menu item 'Sound Card Driver' shows the card currently being seen by the software. Select the driver (use an ASIO driver if possible) and the input and output channels.

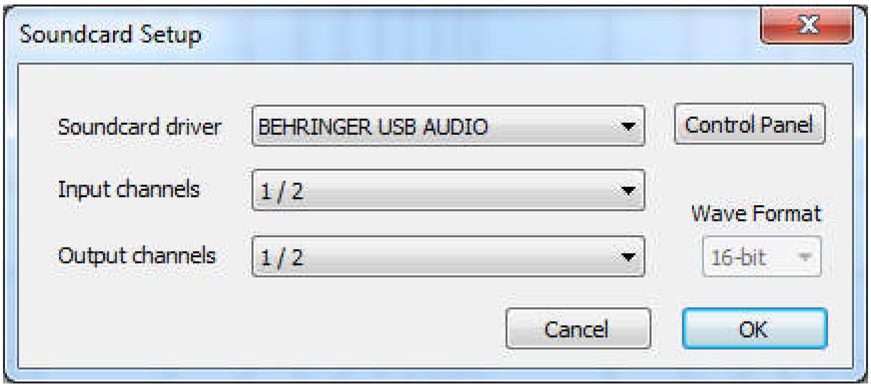


Figure 2.2.3 Soundcard setup in LIMP.

Depending on the soundcard drivers available, Windows can open either the Windows mixer or the ASIO Control Panel will open. For LIMP, no further settings are required here.

n.b. In Measurement Setup, as a rule you should only need to enter the value of the reference resistor. All other settings can be left as their defaults.

There are three setup areas for LIMP:

- Measurement Config (left)
- Stepped Sine Mode (middle)
- FFT Mode (pink noise excitation) – (right)

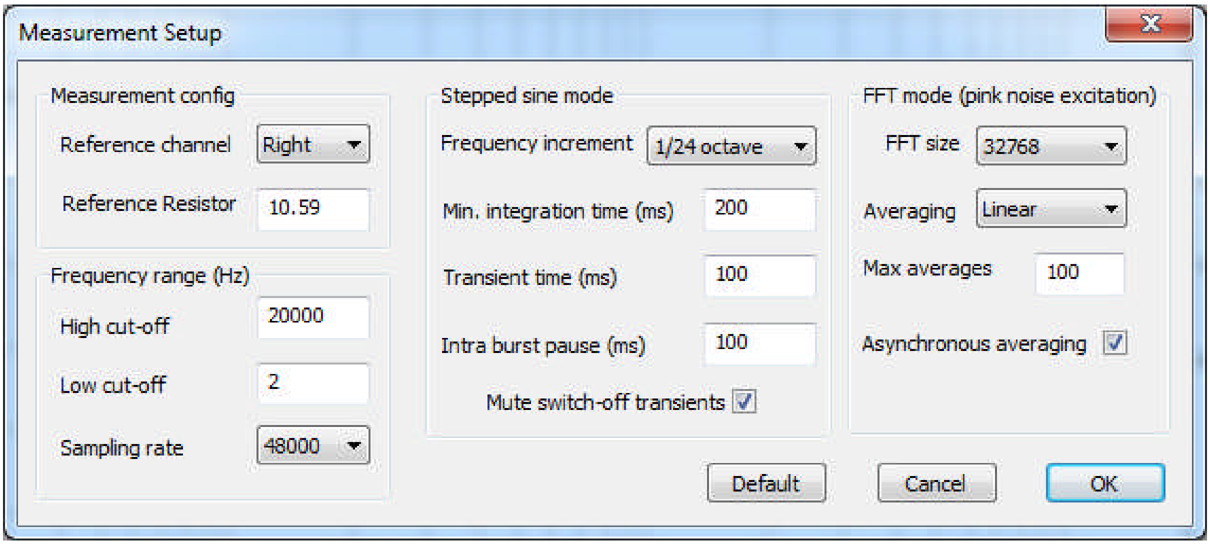
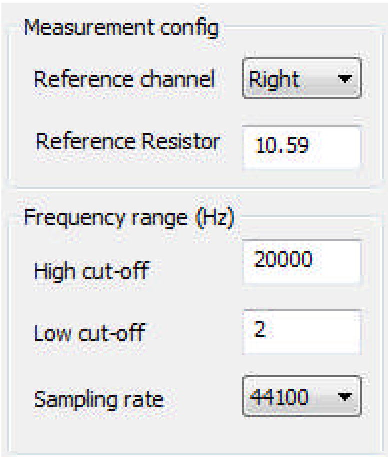


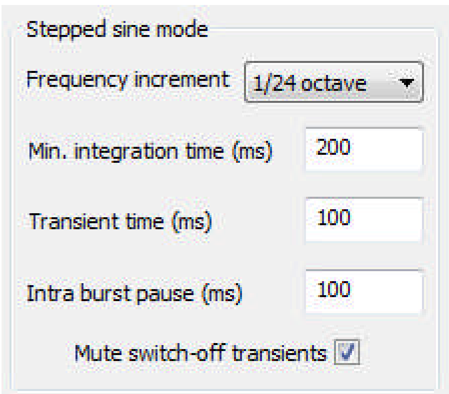
Figure 2.2.4 Measurement Setup.

General measurement parameters are defined under 'Measurement Config':



- Reference channel: default is the right input channel
- Reference Resistance: see sections 2.1.1 and 2.1.2: **the exact value must be determined by measurement**
- Upper frequency limit: see below
- Lower frequency limit: see below.

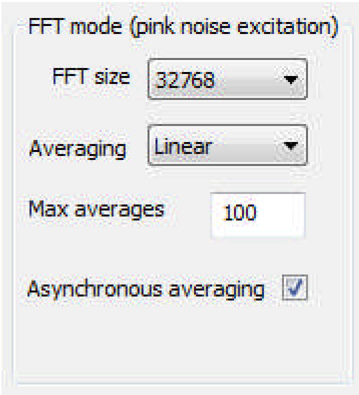
The frequency limits can also be controlled via the top menu



In stepped sine mode, the parameters for excitation with the stepped sine signal are defined.

All parameters for this part of the program are set out in ARTA Handbook Section 9.1. The default settings are suitable for usual impedance measurements.

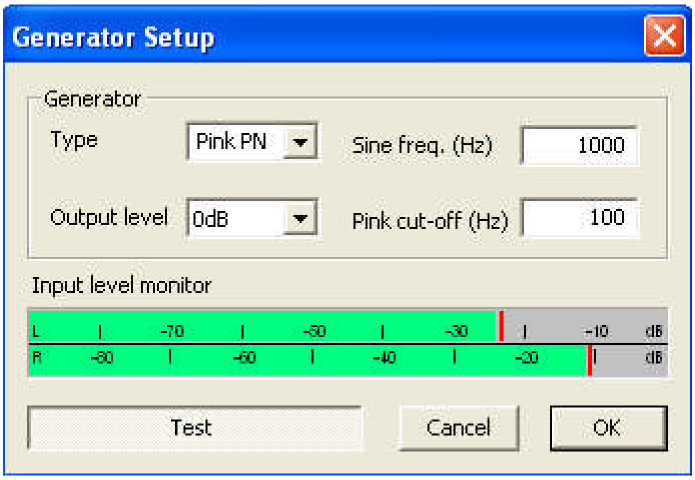
Mute switch-off transients: mutes the 'clicks' at the end of each sine wave packet.



In FFT mode, parameters for pink noise excitation can be defined.

- FFT size: values for FFT (resolution)
- Averaging: type of averaging (none, linear, exponential)
- Max averages: maximum number of averages
- Asynchronous averaging: asynchronous averaging on/off

Before measuring, check the output level so as not to overdrive the input channels. The two excitation signals are very different, so when the signal type is changed levels should be verified. All necessary settings can be accessed via the menu item 'Generator Setup'.



Generator

- Type of excitation: PN or stepped sine
- Output level: 0 to –20dB
- Frequency of sine excitation
- Cut-off frequency of pink noise signal.

Input Level Monitor

Click on 'Test'. If the display shows red or yellow, the level should be reduced.

Soundcard calibration

The soundcard is calibrated using 'Calibrate Input Channels'. The process is very simple.

If using the ARTA Measuring Box, move the switch SW1 of the Box to the Impedance Measurement position, and SW2 to the Imp Cal position.

Click on CAL in the top menu bar to open the 'Calibrate Input Channels' dialogue and calibrate the system.

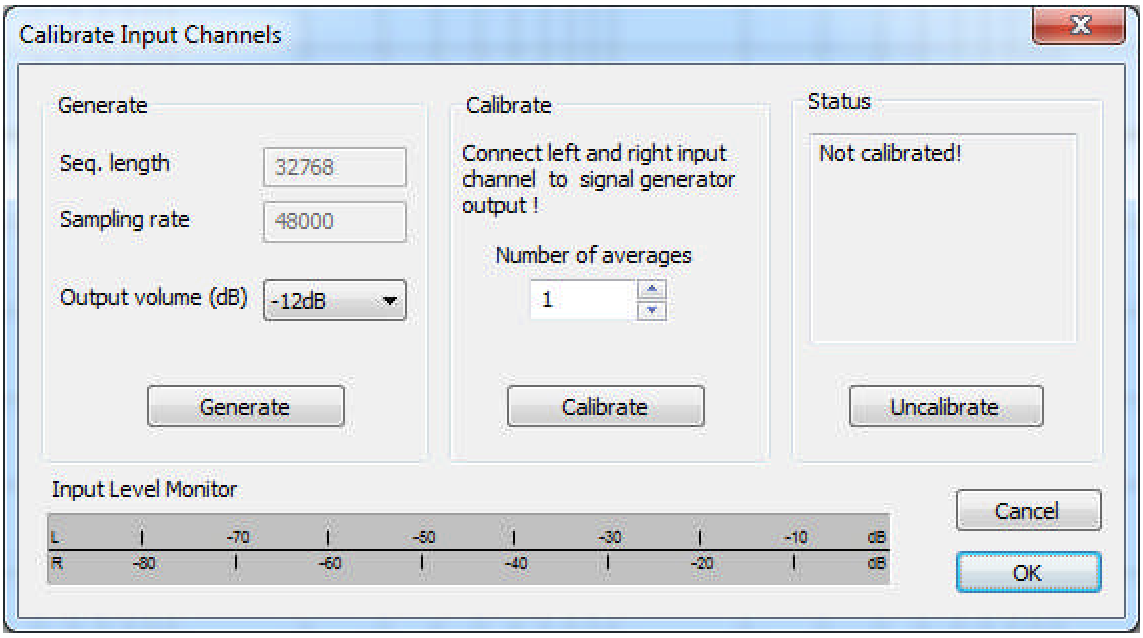
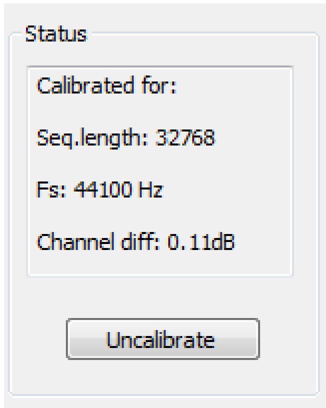


Figure 2.2.5 Measurement Setup.



The Generate button generates the signal so that the levels can be checked. The Calibrate button then calibrates the two input channels relative to each other. When calibration is complete, the status window shows 'Not Calibrated' or 'Calibrated for', with the sequence length, sampling frequency and measured channel difference shown.

Note. The calibration is valid only for the selected settings. If you change the sampling rate or the length of the FFT sequence, you **must** recalibrate.

The channel difference is compensated for by the software. If the measured difference is >2dB, you will get an error message (Figure 2.2.6).

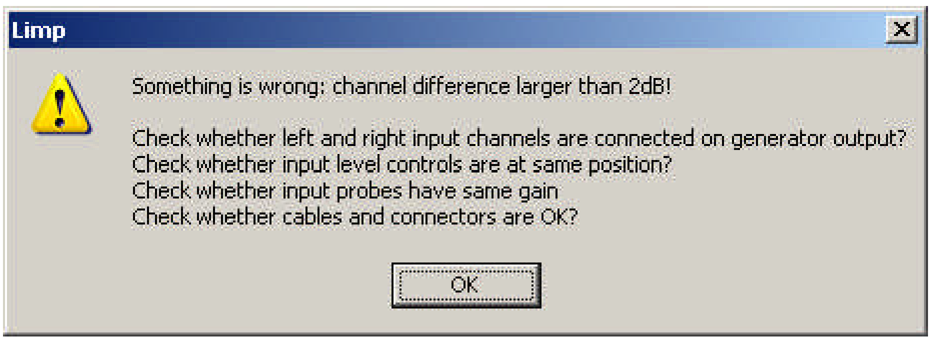


Figure 2.2.6 Channel calibration error message.

The error message suggests possible causes for the excessive channel difference.

- Correct reference channel (Figures 2.1.2, 2.1.6 and 2.2.4)?
- Same gain for both input channels (see ARTA Handbook Section 2)?
- Voltage dividers equal (if present)?
- Cables and connections OK?

2.2.2. *Compensating for the test leads*

A general principle is to keep all leads as short as possible. If you do that, you can probably skip this section.

Even the shortest copper wire has some resistance (0.017241 $\Omega mm^2/m$. Figure 2.2.7 shows the impedance response of different copper test leads.

From the top: 5.5m of 2.5 mm^2, 4m of 4 mm^2, 0.9m of 4 mm^2 (red = ARTA Measuring Box with Rref = 20 ohms; blue = headphone output with Rref = 68 ohms).

Depending on the length and cross-section, values of 0.03 Ω to 0.23 Ω are recorded. The measured values cannot be accounted for entirely by the resistance of the cables only. Contact resistance in switches, terminals and banana plugs also contribute, as shown by the example of the ARTA measurement box when compared with the headphone version.

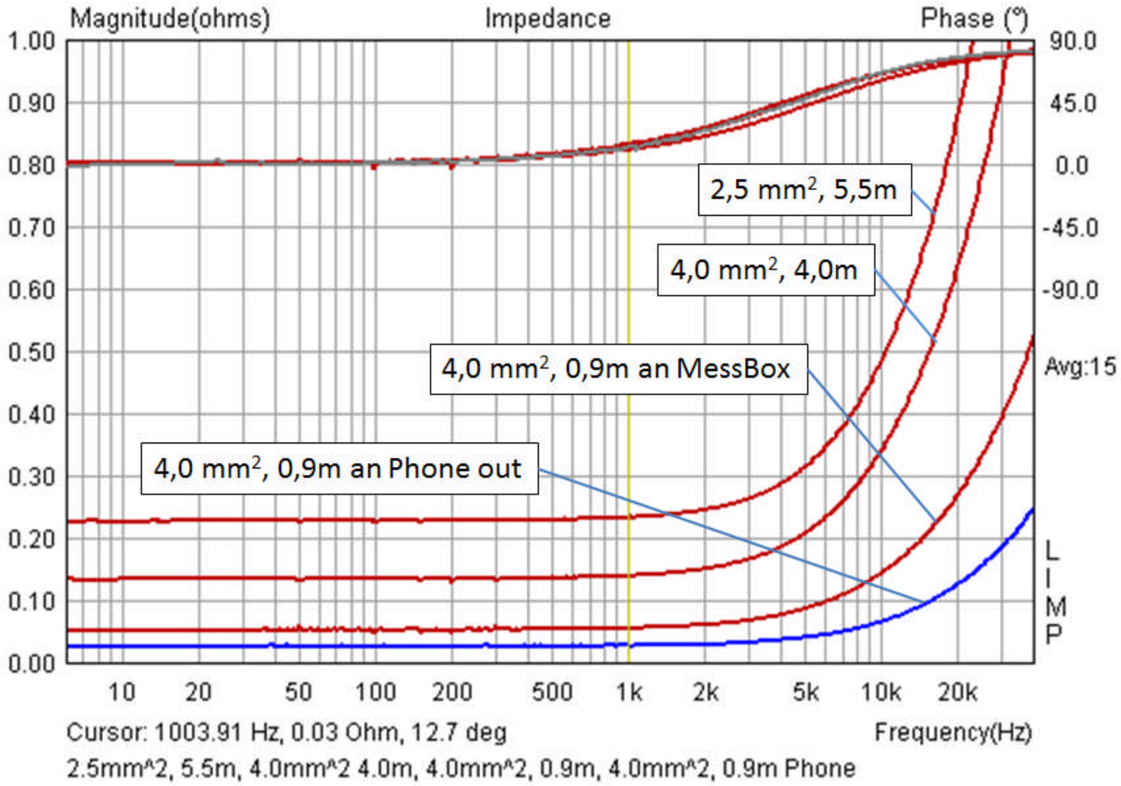
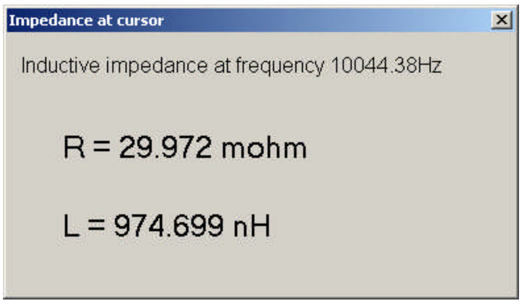


Figure 2.2.7 Impedances of various measurement setups.



We can compensate for cable resistance by using the 'Cable Impedance Compensation' function. To do this, the shorted test lead is measured. The reading should be similar to that shown in Figure 2.2.7. Place the cursor at approximately 45° of phase and click the RLC button in the main menu bar. The 'Impedance at cursor' window appears, showing the resistance and the inductance at the cursor position. These values are transferred to 'Cable Impedance Compensation' (Figure 2.2.8). Note the units! If the checkbox 'Automatically subtract cable impedance from Measured Impedance' is activated, each measurement is automatically corrected for the impedance of the cables.

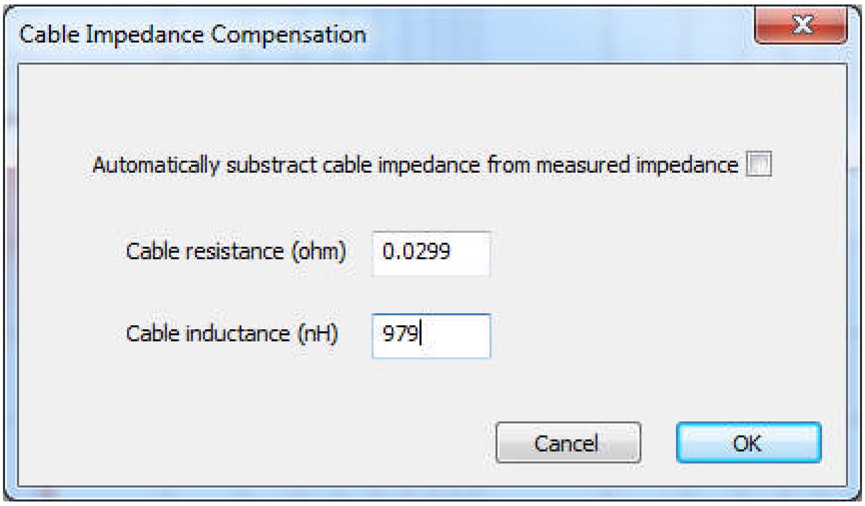


Figure 2.2.8 Cable compensation menu.

An alternative method for compensating for the test leads is by using the 'Subtract Overlay' function. This is a 'zero measurement' of the test lead stored as an overlay and subtracted from each measurement.

3. Determination of TS parameters

LIMP supports two methods for determination of TS parameters:

- Volume method (closed box of known volume; Figure 3.1.1a)
- Added mass method (Figure 3.1.1b)

In principle, both methods are equivalent, but the volume method is preferred if the resonance frequency, Fs, of the speaker is very low. The added mass method is much easier as you do not have to construct a box; instead you simply add mass to the driver. Added mass will be accurate as long as the Fs is not below 25Hz or so as most soundcards start to lose accuracy at very low frequencies.

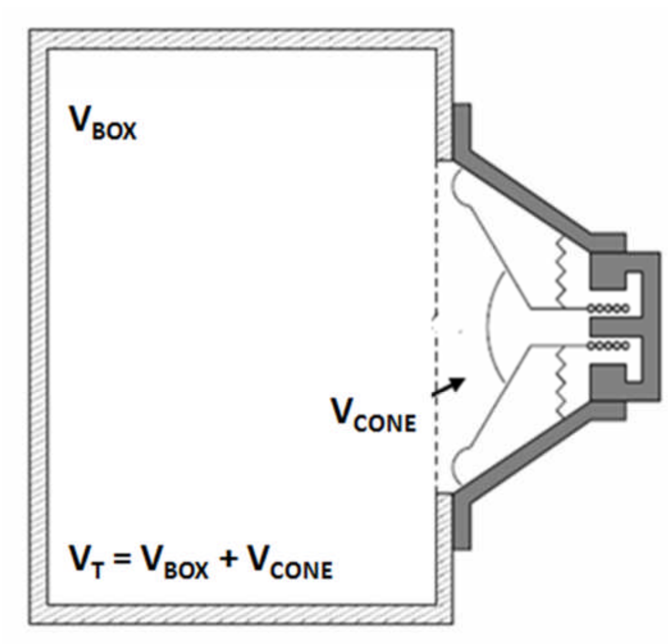


Figure 3.1.1a Volume (closed box) method.

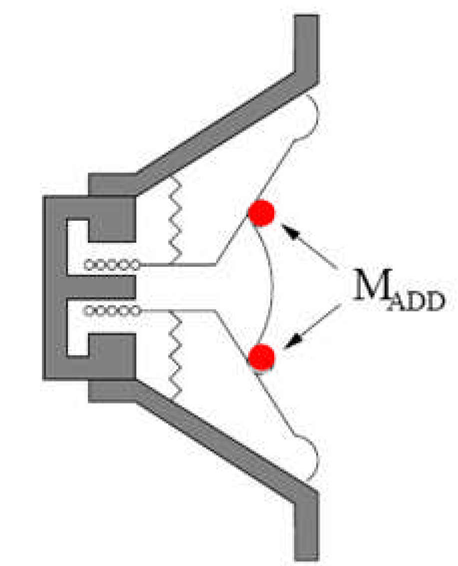


Figure 3.1.1b Added mass method.

3.1. Preparation for TS parameter measurement

Before measuring, it is worth reading the seminar 'Loudspeaker Parameters' by Neville Thiele and Richard Small that was given in 2008 (2) and the guidance issued by a well-known driver manufacturer (3). Among other topics, the seminar addressed the conditions for the determination of TS parameters (signal strength, measurement position, mounting or clamping conditions) and driver break-in.

3.1.1. Excitation signal strength

Remember that TS parameters are measured using small signals! Small recommends limiting the signal to a level just sufficient to ensure a clean measurement. SB Acoustics, in their Technical Note (3), recommend approximately 1 volt for measuring midrange speakers at their resonance frequency. The default AES2-2012 standard (4) recommends 0.1 volts for typical measurements.

As mentioned earlier, the energy contents of the available excitation signal types in LIMP (PN, stepped sine) differ. Figure 3.1.2 shows impedance curves for both excitation signals with identical gain. The red curve is the stepped sine and the black curve is pink noise. The more energy-rich sinusoidal signal gives a lower apparent resonance frequency.

Shifting resonance frequency with changing excitation amplitude is a well-known phenomenon (C_{MS} is not a constant), and different strength excitation signals and different measurement methods should not therefore be expected to yield the same results.

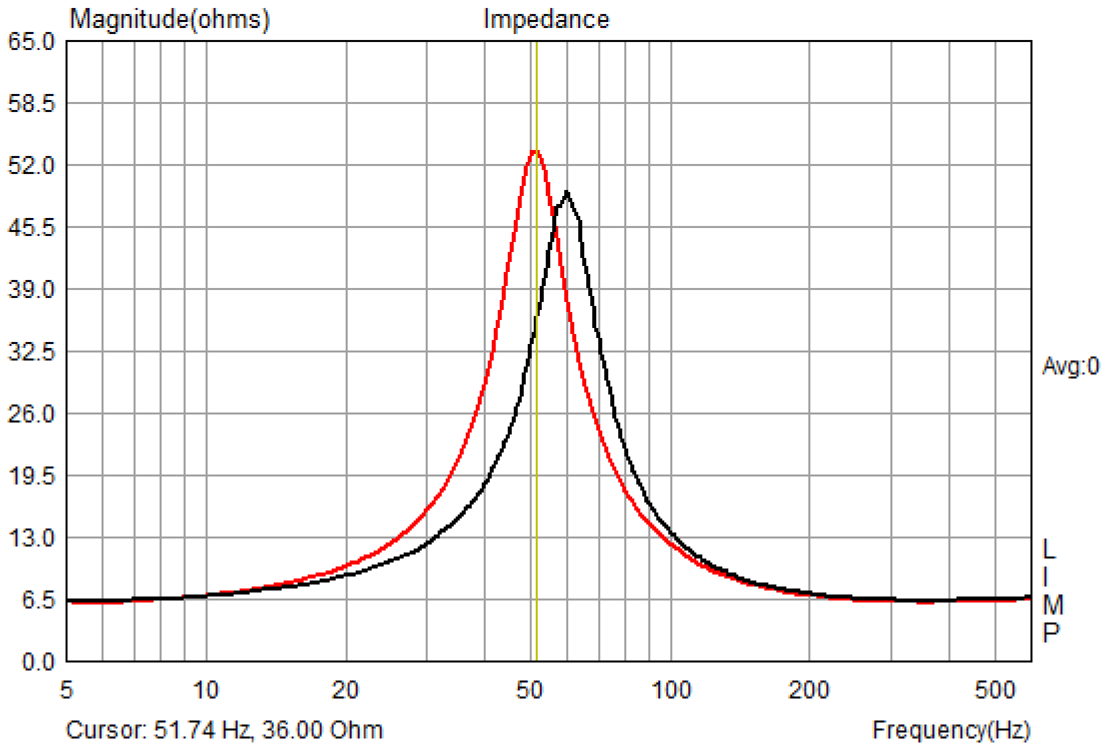


Figure 3.1.2 Impedance with different excitation signals (red = stepped sine; black = PN).

It is important to check if the parameters are consistent to ensure accurate calculation/simulation. Hi-Fi Selbstbau in Cologne offer a useful tool called 'TSP-Check' (5). Alternatively, the Fs/Qts ratio can give a rough indication as to whether results are reliable.

3.1.2. Driver break-in

AES2-2012 recommends that loudspeakers must be driven for several minutes before measuring TS parameters to in order to avoid drifting resonance frequency readings (4). SB Acoustics (3) drive their speakers for about 10 minutes with a sinusoidal signal at around 0.8 times the Fs. The voltage is chosen so that the speaker operates with maximum deflection. The driver should be allowed to cool to room temperature afterwards before measurements are taken. Other sources suggest a break-in period of several hours. Conversely, Vance Dickason suggests that break-in is required only for the early detection of hidden defects in the driver (6).

3.1.3. Speaker mounting

Small recommends that the driver under measurement be firmly clamped in position (Figure 3.1.5). In his presentation he demonstrated the effects of unwanted/unintentional influences on a mass-spring system.

Figure 3.1.3 shows the effect of mounting the driver on a firm (MDF; red) or soft (foam; blue) surface horizontally or vertically. The driver in the left panel has an apparent membrane mass of 11g, while that on the right is 43g. An additional resonance is also produced by mounting on the foam substrate.

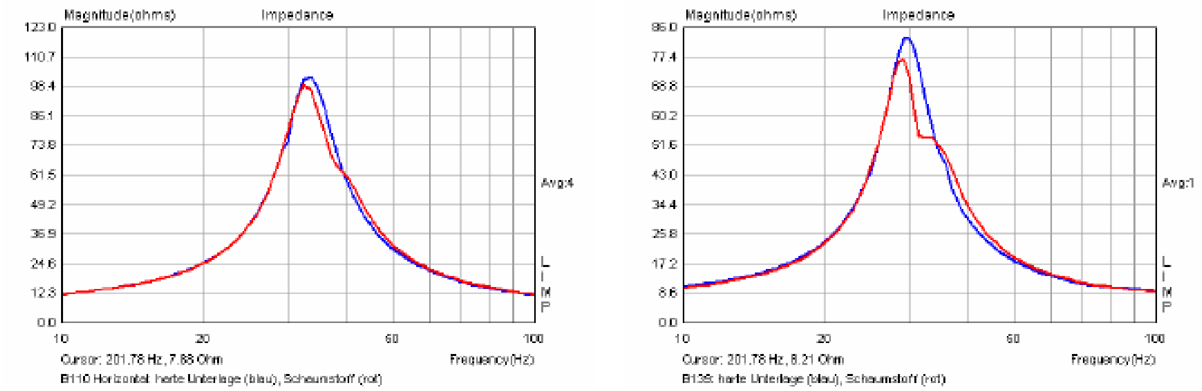


Figure 3.1.3 Influence of the mounting surface on speaker measurements (red = foam, blue = MDF)

Figure 3.1.4 TS parameter measuring positions.

Driver mounting is a subject discussed frequently on forums, and various arrangements have been suggested. Regardless of the opinions expressed, the fact remains that any driver mounted vertically (Figure 3.1.4) will have its voice coil position shifted by the force of gravity (F=mg, where g=9.81 m/s^2. Small and others (2)(7) therefore recommend mounting on the horizontal axis (Figure

3.1.4) in arrangements similar to those shown in Figure 3.1.5. Those who wish to perform repeated measurements should consider the construction of permanent, rigid and sufficiently heavy jigs for driver mounting.

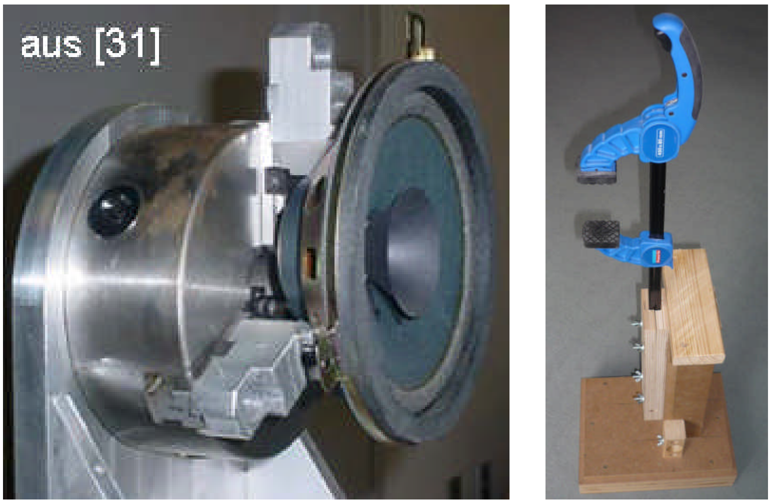
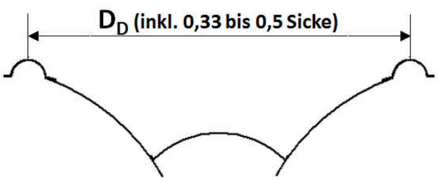


Figure 3.1.5 Jigs for TS parameter measurement.

See the ARTA Hardware and Tools Manual (currently available in German only (1)) for more information.

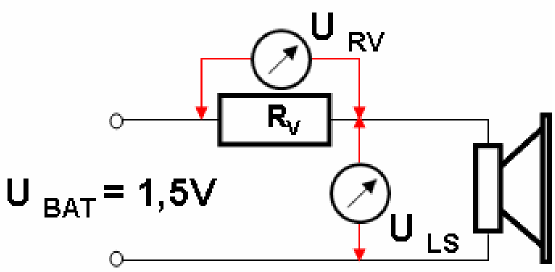
3.1.4. S_D *measurement*

For TS parameter calculation, the effective membrane area S_D or effective diameter D_D must be known. Because the membrane surround also participates in driver resonance, a proportion of this must be factored in. It is usual to include one-third to one-half of the speaker surround.



3.1.5. R_E *measurement*

The DC resistance (R_E) of the voice coil is needed for the calculation of TS parameters. If you are not sure if your multimeter measures DC resistance accurately, try this trick. It works even with very basic multimeters.



$$R_{DC} = \frac{R_V * U_{LS}}{U_{RV}}$$

- Put a known resistance RV (e.g. 8.2Ohm; 0.25W) in series with the driver.
- Connect a 1.5V battery.

- Use the multimeter to measure the voltage across the resistor RV (U_{RV}) and the voltage U_{LS} across the driver.
- Calculate the DC resistance of the voice coil R_{DC} as shown in the formula above.

Example:

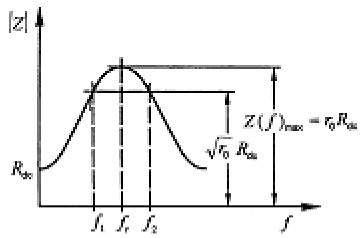
4 Ohm woofer.

- Known: R_V = 4.7 Ohm
- Measured: U_{RV} = 0.8368V, U_{LS} = 0.5591V
- Calculated: R_{DC} = 4.7 * 0,5591/0.8368 = 3.14 Ohm (manufacturer's specification = 3.10 Ohm).

n.b. As of version 1.8, LIMP provides an option for the determination of R_E from the impedance curve (see section 3.2).

3.2. Speaker models for TS parameter determination

As of version 1.8, LIMP provides in addition to the classic method depicted to the right (8)(9)(10) additional functionality for the determination of TS parameters. Detailed information can be found in Mateljan & Sokora (9). The following is a brief summary.



In the 'Loudspeaker Parameters' window, the 'User Input' parameters must be determined and entered. These will vary depending on the method chosen (i.e. sealed volume or added mass); see also sections 3.1.4 and 3.1.5.

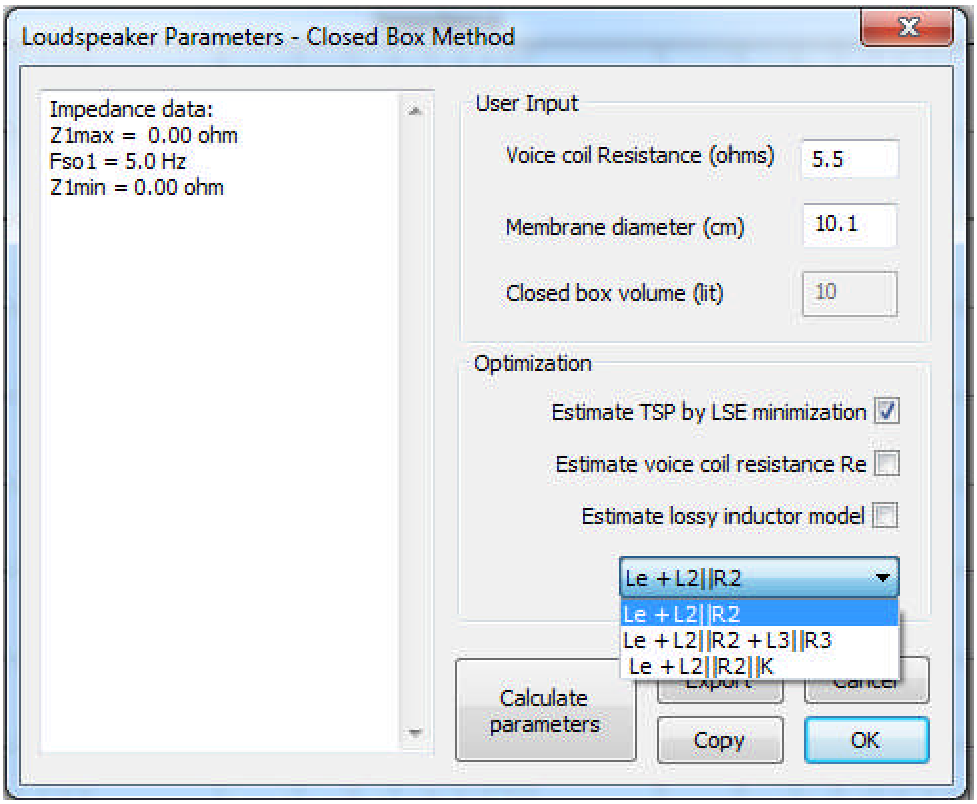


Figure 3.2.1 Loudspeaker Parameters window (Closed Box method shown).

The 'Optimization' area contains three check boxes and a drop-down menu. Use the check boxes to select the type of optimization required:

- Estimate TSP by LSE minimization
- Estimate Voice Coil Resistance Re
- Estimate lossy inductor model

If none of the boxes are checked, the classic method for determining TS parameters is applied (see LIMP User Manual (1), section 5.2.2).

If 'TSP by LSE minimization' is checked, the nonlinear least square error minimization procedure is activated, whereby we minimize the squared difference between the measured impedance Z_M and modelled impedance Z_{LF}. The quality of the optimization can be graphically controlled by using the F3 function key (see Figures 3.2.3a and 3.2.3b).

If 'Voice Coil Resistance Re' is checked, LIMP determines the DC resistance of the voice coil from the measured impedance curve. This is especially useful if no ohmmeter / multimeter is available. Please note that if this box is checked any value entered for Re will be ignored by the software.

Checking 'Lossy Inductor Model' activates a selection of voice coil optimization Z_{LE} equivalent circuit models (drop-down menu).

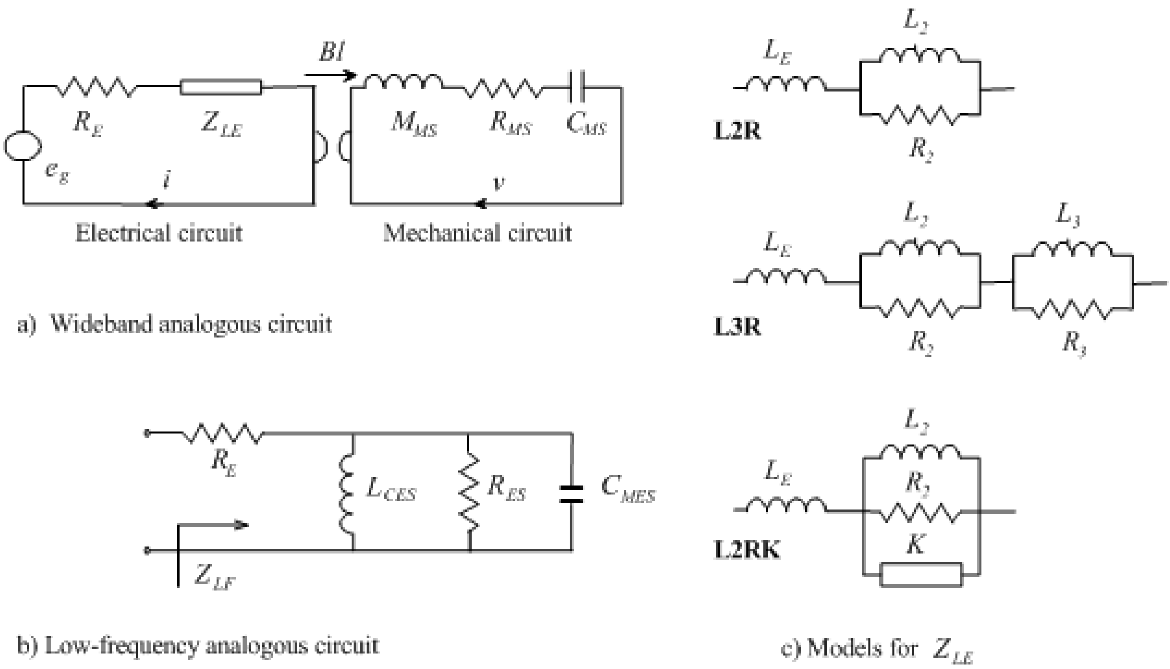
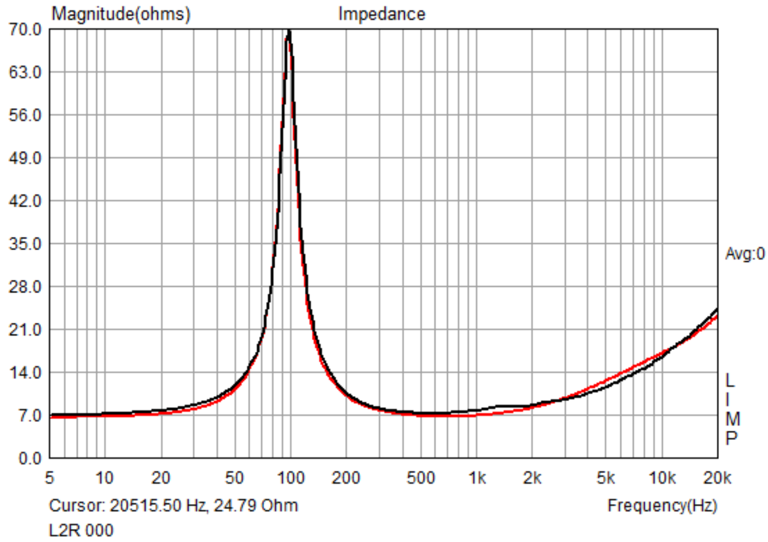


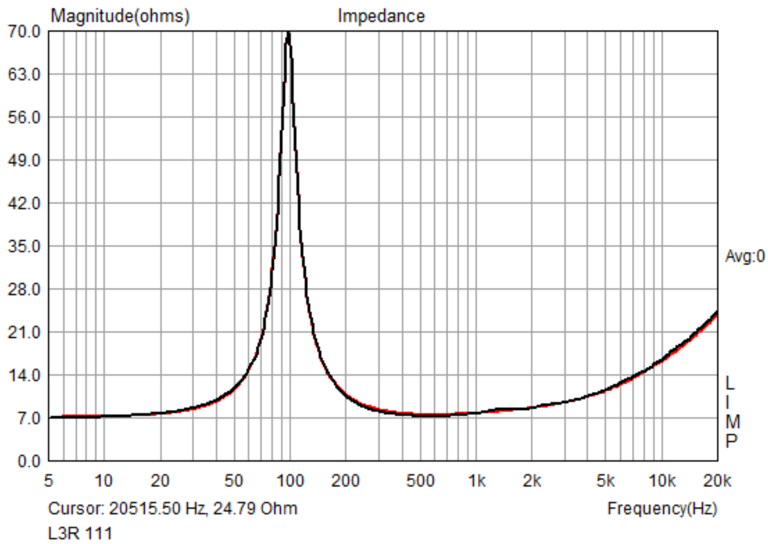
Figure 3.2.2 Equivalent circuit of a loudspeaker with various models for Z_{LE}.

Three different models are available (Figure 3.2.2c). Use of these equivalent circuits in a simulation can improve the goodness of fit of the impedance curve significantly over the entire frequency range.



Loudspeaker Parameters
Fs = 96.94 Hz
Re = 6.60 ohms[dc]
Qt = 0.51
Qes = 0.56
Qms = 5.37
Mms = 2.25 grams
Rms = 0.255123 kg/s
Cms = 0.001197 m/N
Vas = 1.72 liters
Sd= 31.97 cm^2
Bl = 4.011855 Tm
ETA = 0.27 %
Lp(2.83V/1m) = 87.22 dB
fs/Qt = 190,08

Figure 3.2.3a TS parameters and goodness of fit of the L2R model, all optimization parameters inactive.



Loudspeaker Parameters
Fs = 97.66 Hz
Re = 7.07 ohms[dc]
Qt = 0.53
Qes = 0.59
Qms = 5.20
Mms = 1.97 grams
Rms = 0.243228 kg/s
Cms = 0.001369 m/N
Vas = 1.97 liters
Sd= 31.97 cm^2
Bl = 3.902635 Tm
ETA = 0.31 %
Lp(2.83V/1m) = 87.55 dB
fs/Qt = 184,26

Figure 3.2.3b TSP and goodness of fit in the model L3R, all optimization parameters active.

As we can see, the results differ slightly depending on the model selected. The fs/Qt ratio differs by about 3%, and Vas by about 13%. What does this mean in terms of speaker design?

Figure 3.2.3c shows AJH simulations using the parameter sets from Figure 3.2.3a (Model L2R 000 = black) and Figure 3.2.3b (model L3R 111 = red). The difference between the two can be seen quite clearly. If it’s important for the design you have to decide by yourself.

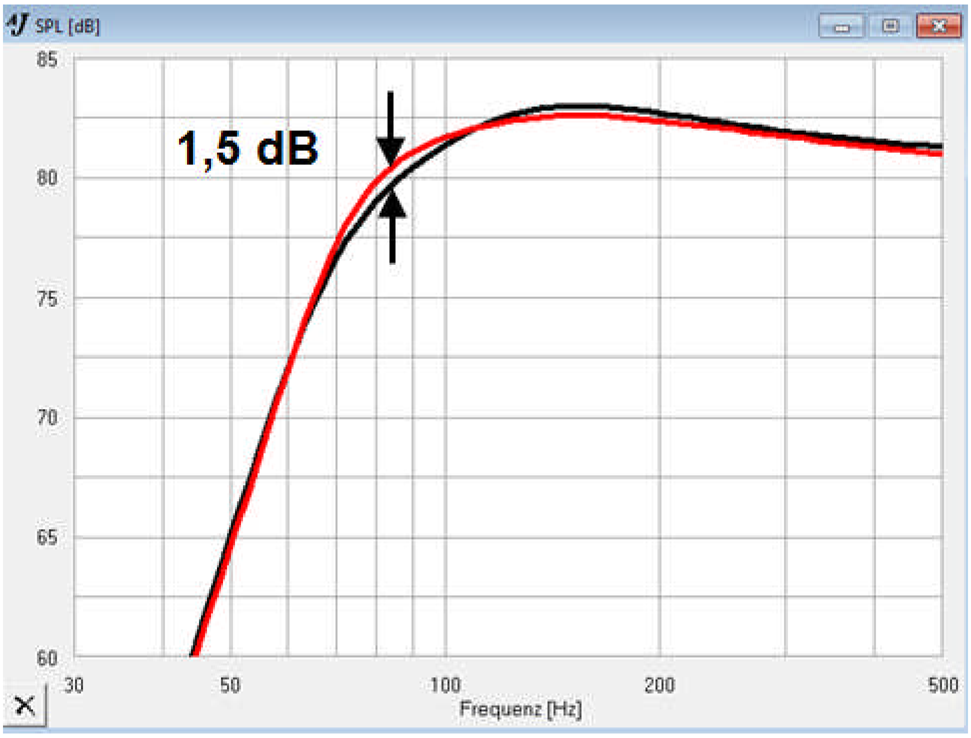


Figure 3.2.3c Simulation results using parameter sets from Figures 3.2.3a and 3.2.3b.

3.3. TS-parameter determination: volume method

Determination of TS-parameters using the volume method is carried out as follows:

1. Calibration (section 2.2.1)

2. Set test volume.

D [cm]	VT [Ltr]
8	3
10	5
13	7
17	12
20	17
25	30
30	55
38	140

A well sealed test box of known volume with an aperture over which the inverted driver can be placed is needed. A rough estimate of the required volume can be made using the table (left). The volume of the enclosure needs to be such as to cause a 20–50% shift in the resonance of the loudspeaker. Parameter inputs are controlled in LIMP (Figure 3.3.2).

For example, a 17cm driver will need a box of around 12L. Bear in mind that when entering the parameters into LIMP the exact volume to include the space taken up by the inverted cone will be needed (Figure 3.1.1a).

3. Measure the driver's impedance in free air.

4. Save the free air impedance using 'Overlay' then 'Set' (yellow trace).

5. Repeat the impedance measurement in the test housing (closed box: Figure 3.1.1a).

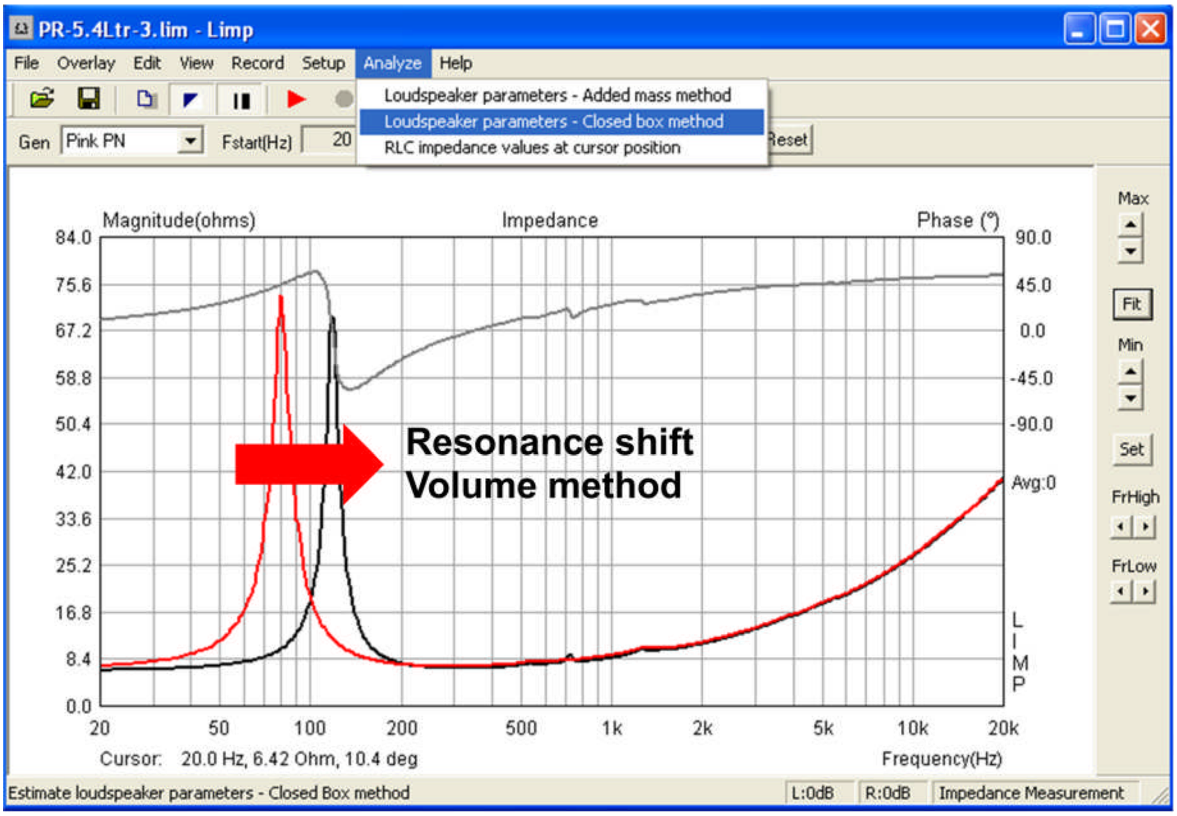


Figure 3.3.1 Impedance of driver in closed box (black) and free air (red).

6. Analyze driver parameters.

Go to 'Analyze' and 'Loudspeaker parameters - Closed box method' as shown above; you will need to enter the 'User Input' parameters required (see also section 3.1).

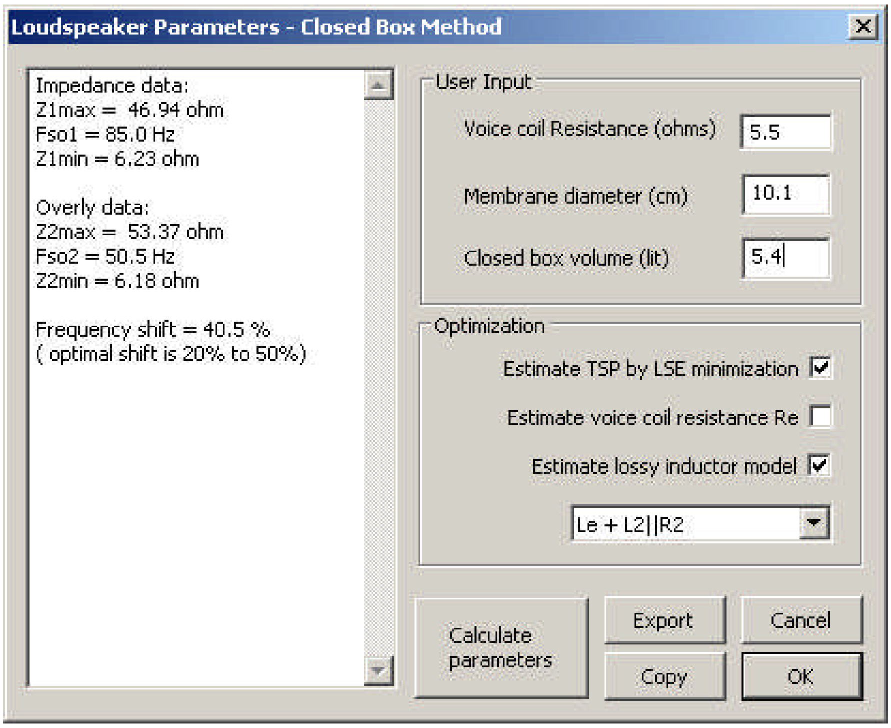


Figure 3.3.2 Calculating TS parameters.

If the input fields are greyed out and will not accept data, this means that no overlay has been defined.

Click 'Calculate' and LIMP will estimate the TS parameters (Figure 3.3.3).

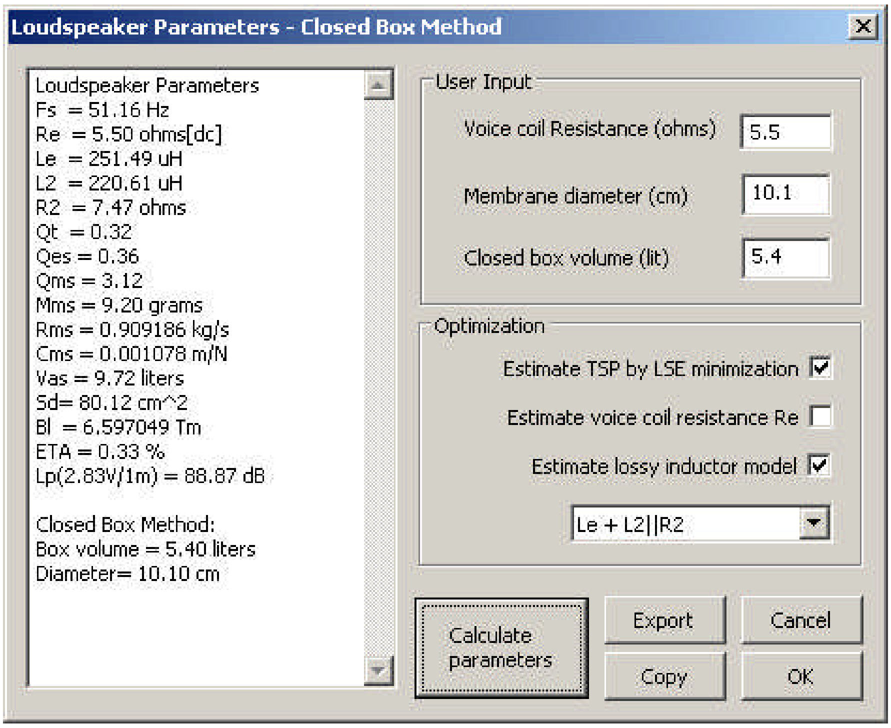


Figure 3.3.3 Calculated TS parameters.

7. Copy.

Use 'Copy' to copy the data to ASCII files. The output is as follows:

Thiele-Small Parameters:

- Fs = 79.85Hz
- Re = 5.75Ohms [dc]
- Qt = 0.63
- Qes = 0.68
- Qms = 8.02
- Mms = 13.47g
- Rms = 0.842902kg/s
- Cms = 0.000295m/N
- Vas = 6.64L
- Sd= 126.68cm^2
- Bl = 7.555168 Tm
- ETA = 0.48%
- Lp(2.83V/1m) = 90.33dB

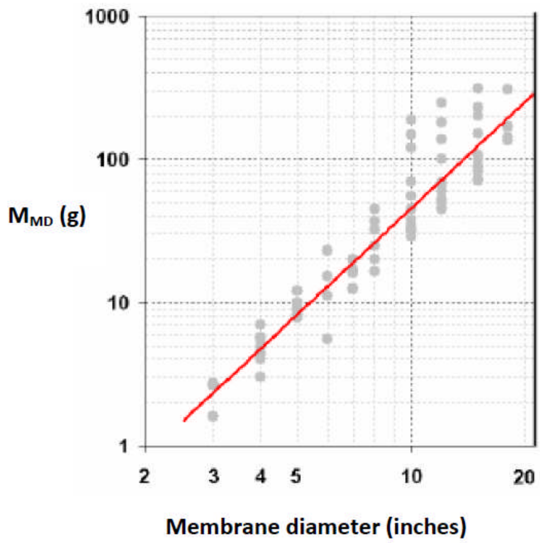
Closed box method:
Box volume = 5.40L
Diameter = 12.70cm

3.4. TS-parameter determination: added mass method

1. Calibrate.

2. Specify test mass.

The mass to be added depends on the diameter (membrane area) of the driver. As with the previous method, a resonance shift of between 20% and 50% is needed. Adding mass of the order of the membrane mass M_{MD} will give an approximate decrease in resonant frequency of 30%. If you do not know the M_{MD} of your driver, the diagram to the right will give a rough estimate.



Example: an 8-inch driver will have M_{MD} of 15–50g. A 25g weight should be trialled for the first measurement.

Points 3 and 4 are as for the volume method above.

5. Measure impedance with the added mass (Figure 3.4.1).

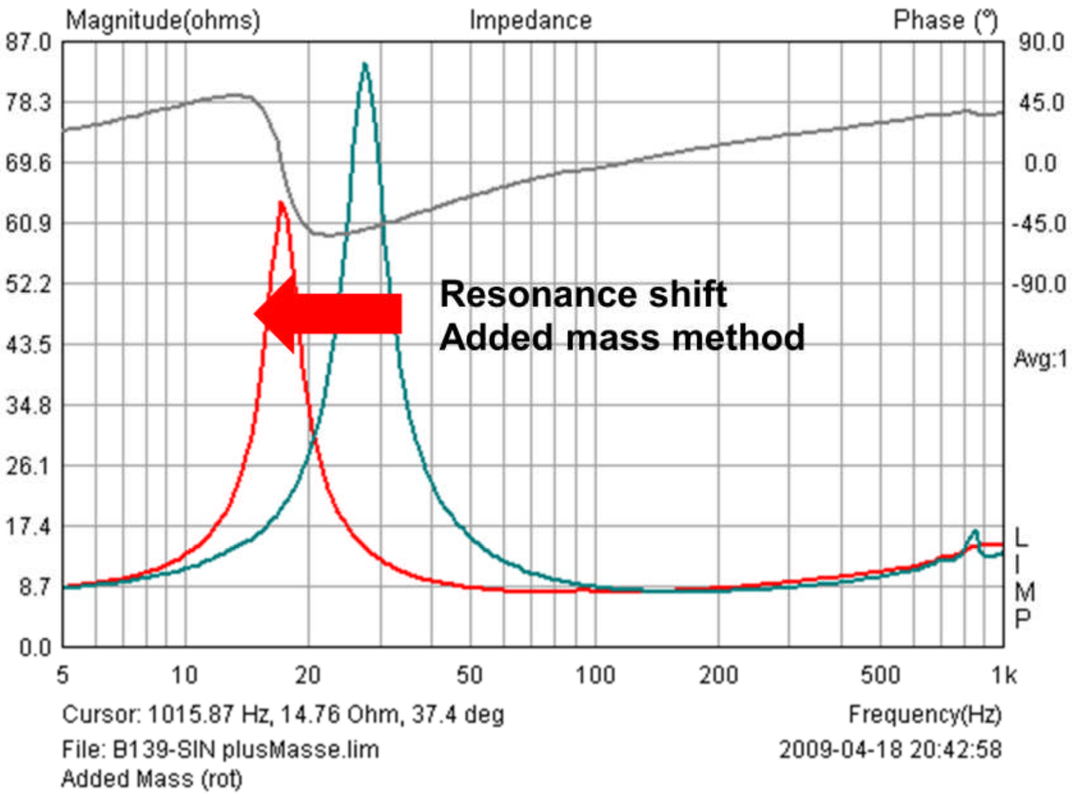


Figure 3.4.1 Driver impedance with (red) and without (green) added mass.

6. Get TS parameters.

Similarly to the previously described volume method, click on 'Analyze' but then choose 'Loudspeaker parameters - Added Mass Method. Enter the 'User Input' data required

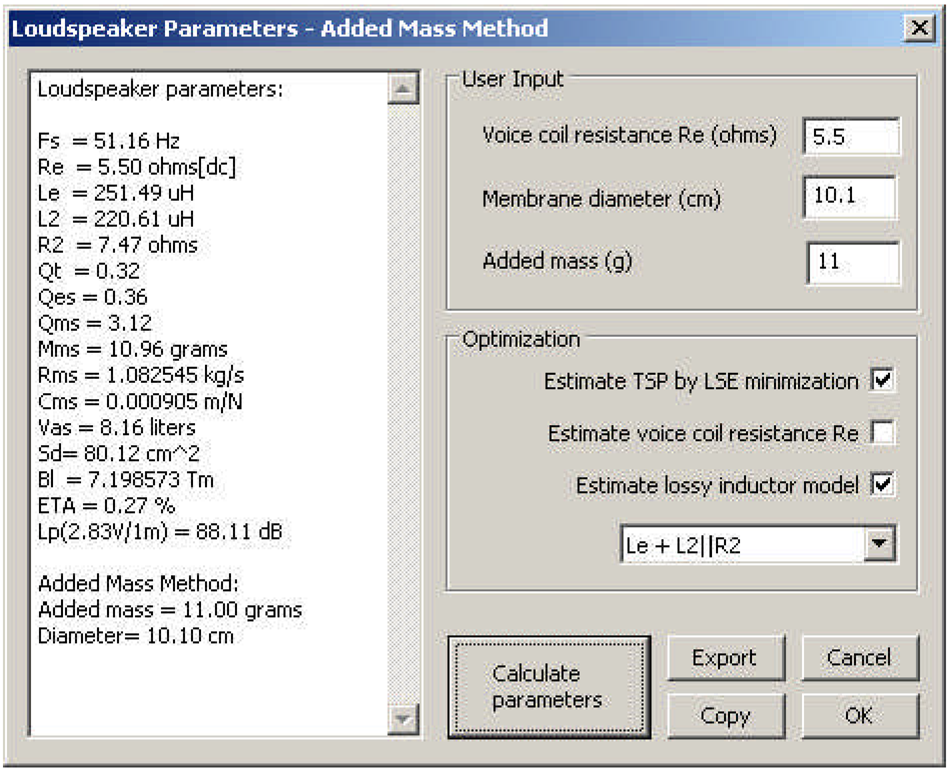
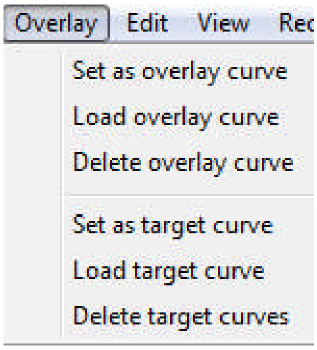


Figure 3.4.2 Estimation of TS parameters using the added mass method.

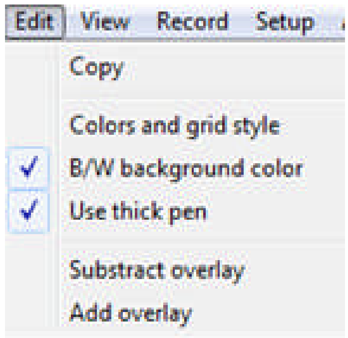
7. Copy.

Export the data using 'Copy to Clipboard' or 'Export in CSV file'. If you intend to apply statistical analysis to the data, use the CSV option as it gives you immediate access to full Excel functionality.

4. Working with overlays and targets in LIMP



As of Release 1.8, the LIMP ' Overlay' menu provides for targets and overlays. The 'Set as Overlay' function allows the loading of overlays only. Reactivation of the function loads the current curve as an overlay and deletes the previous overlay automatically. This restriction is in place because the overlay function in LIMP is intended primarily for the calculation of TS parameters. The 'Set as target' function allows the use to load numerous targets, although they are all shown in the same color.



Two additional simple arithmetic functions are included in the 'Edit' menu: 'Add Overlay' and 'Subtract Overlay'. An example of an application for 'Subtract overlay' has already been covered, i.e. compensation for test leads as described earlier.

This new functionality opens up possibilities for, among other things, quality assurance measures. Examples include the selection of loudspeaker drivers, auditioning PA hire equipment, etc. Some examples and usage tips follow.

Product selection or testing requires assessment against prespecified tolerances and limits. We can do this in LIMP by importing text files with .txt or .zma suffixes. These can be generated using a text editor or MS Excel as follows.

freq	*mag*	*phase*
91.1	*0.0*	*0.0*
91.1	*22.0*	*0.0*
116.9	*0.0*	*0.0*
116.9	*22.0*	*0.0*

Table 4.1 ZMA data representing tolerance limits (fs = 104 ± 12.9 Hz - see vertical red lines in Figure 4.1).

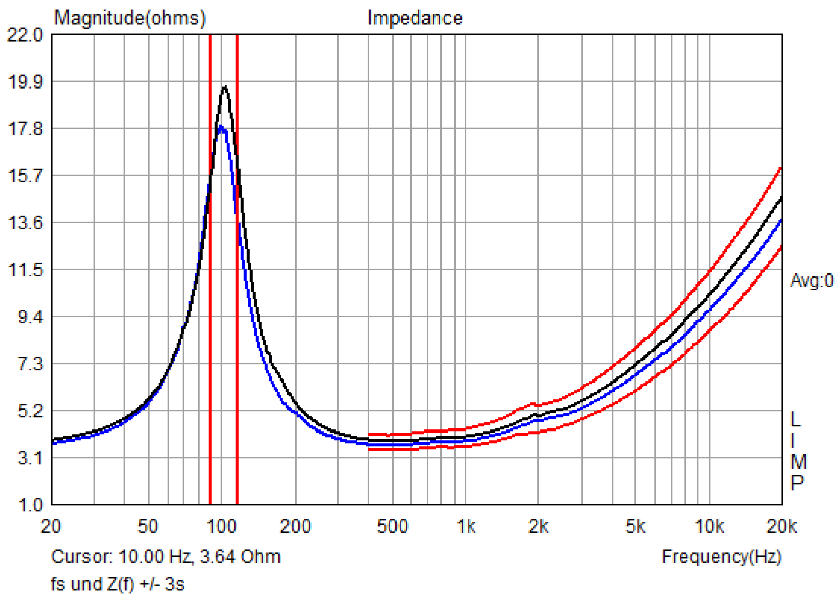


Figure 4.1 Tolerance limits on a loudspeaker impedance curve.

Impedance profile slopes can also be used to set tolerance limits (Figure 4.1).

Figure 4.2 shows the measurement of the resonance frequencies of 32 small woofers. From a previous batch, the resonance frequency fs was believed to be 104 ± 12.9 Hz. Using 'Load target curve', the tolerance values from Table 4.1 were imported as a ZMA file.

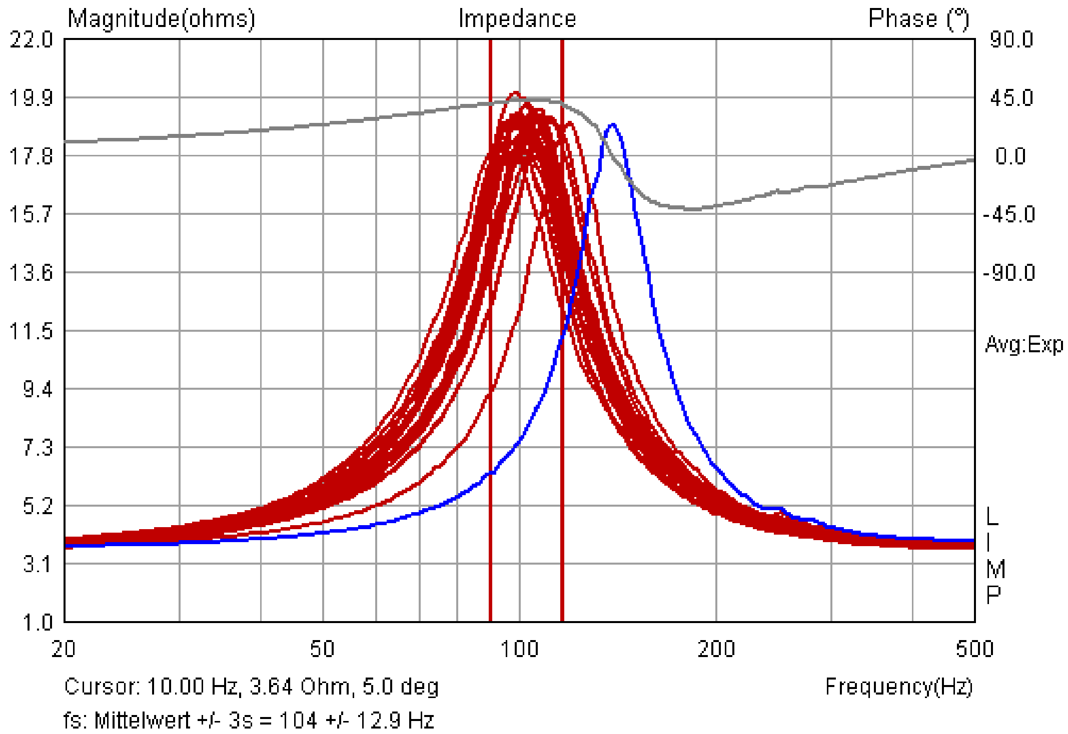


Figure 4.2 Loudspeaker selection, tolerance limits Fs ± 3s.

5. Using LIMP as an RLC meter

LIMP determines the value of resistors, capacitors and coils by calculating the resistive, inductive or capacitive component of the impedance. Figure 5.1 shows an example of the impedance curve of a coil with a nominal inductance of 0.33mH.

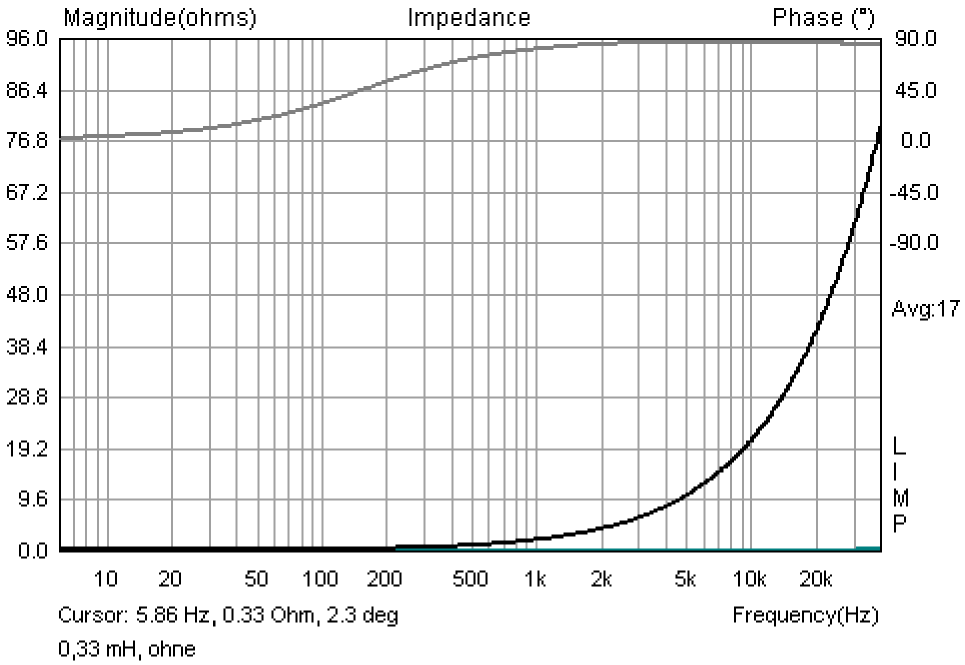
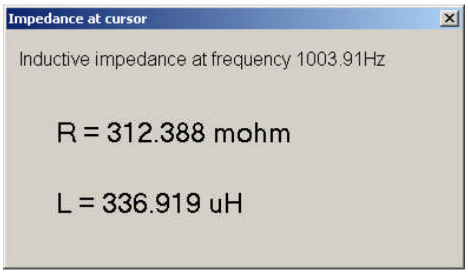


Figure 5.1 Impedance trace of a 0.33mH inductor.



The operation 'Analyze' followed by 'RLC Impedance values at cursor position' yields the result shown on the left.

LIMP tells us that the measured impedance at the cursor position has a resistive component of 0.312 ohms and an 'imaginary' inductive component of 0.336mH. Capacitors and resistors can be measured in a similar fashion.

When carrying out RLC measurements it is important to calibrate beforehand. This is because even with small differences in sensitivity of the input channels of the sound card (e.g. 0.1dB), LIMP may under certain conditions give spurious results because of phase errors.

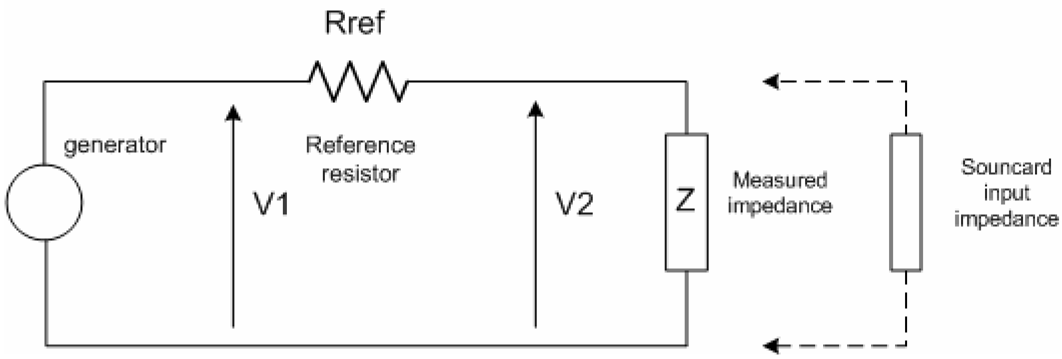


Figure 5.2 Setup for impedance measurement.

In the event that the measurement of voltage V1 across the generator and voltage V2 across the impedance Z is corrupted due to differences in sensitivity of the two measuring channels, a phase value greater than 90 degrees may be detected which can lead to a 180-degree phase reversal (Figure 5.3).

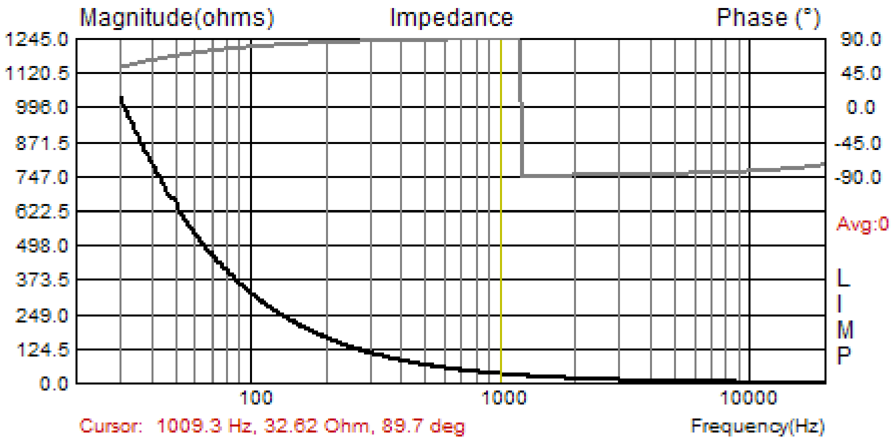


Figure 5.3 Uncalibrated impedance determination for a capacitor of 4.7µF/250V.

Figure 5.3 shows the result of a capacitance measurement without calibration. Until about 1200Hz, the phase runs at nearly +90 degrees and so gives the impression that the component is an inductor. After calibration, the phase behaves as expected over the entire frequency range (Figure 5.4).

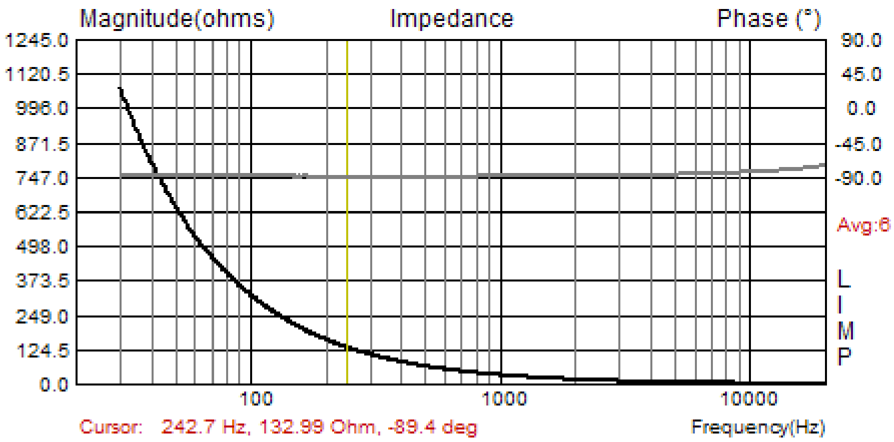


Figure 5.4 Calibrated impedance determination of a capacitor of 4.7µF/250V.

Not all LIMP-users will have the above problem because it is present only when the voltage V2 across the impedance is higher than the voltage V1 across the generator. To get around this, the sensitivity of the test probe can be changed or the input channels exchanged. If the latter is done, the reference channel set for ARTA in the measurement setup must also be changed.

In order to obtain correct capacitance and inductance values, the cursor should be set to a frequency at which the impedance is less than 100 Ohms. This ensures that the measurements stay within the range of about 1% tolerance. (for further details see section 6).

The following examples demonstrate the performance of LIMP as an RLC-meter compared with a 4-wire RLC meter (TH2821) and a mid-range RLC meter (PEAKTECH PT2165). Measurements were taken with a mid-range sound card (EMU Tracker Pre) via the headphone jack without a voltage divider (see also section 6). All values with the exception of two small inductors were within 1%. The inductor measurements were notable in that the PEAKTECH PT2165 gave almost exactly the same results as LIMP, even for the inductors that were outliers with the TH2812 (0.18mH and 0.33mH).

Type	Nominal value (uF)	LIMP	PT2165	TH2821	∆ TH2821
Smooth bipolar	4.7	4.675	4.674	4.678	-0.06%
Smooth bipolar	8.2	8.745	8.739	8.755	-0.11%
Smooth bipolar	33	34.328	34.300	34.390	-0.18%
Smooth bipolar	47	49.064	49.070	49.140	-0.15%
Rough bipolar	150	172.948	173.150	172.260	0.40%
Rough bipolar	330	363.039	364.800	360.800	0.62%
Rough bipolar	560	547.577	556.300	548.400	-0.15%
Rough bipolar	1000	998.007	1035.700	992.100	0.59%

Table 5.1 Capacitor values: LIMP vs RLC meters.

Type	Nominal value (mH)	LIMP	PT2165	TH2821	∆ TH2821
Air core	0.18	0.183	0.181	0.188	-2.87%
Air core	0.27	0.270	0.269	0.272	-0.66%
Air core	0.33	0.337	0.337	0.345	-2.30%
Air core	0.47	0.479	0.477	0.482	-0.74%
Air core	0.82	0.834	0.833	0.840	-0.75%
Air core	1.20	1.229	1.228	1.234	-0.44%
HQ40/30	1.50	1.548	1.531	1.537	0.69%
Air core	1.50	1.520	1.519	1.526	-0.36%
Air core	1.80	1.833	1.833	1.835	-0.13%
Variable Coil	2.20	2.200	2.200	2.210	-0.44%
Variable Coil	2.70	2.710	2.705	2.716	-0.24%
Variable Coil	10.00	10.014	10.003	10.040	-0.26%
Variable Coil	14.50	14.514	14.494	14.543	-0.20%

Table 5.2 Inductor values: LIMP vs RLC meters.

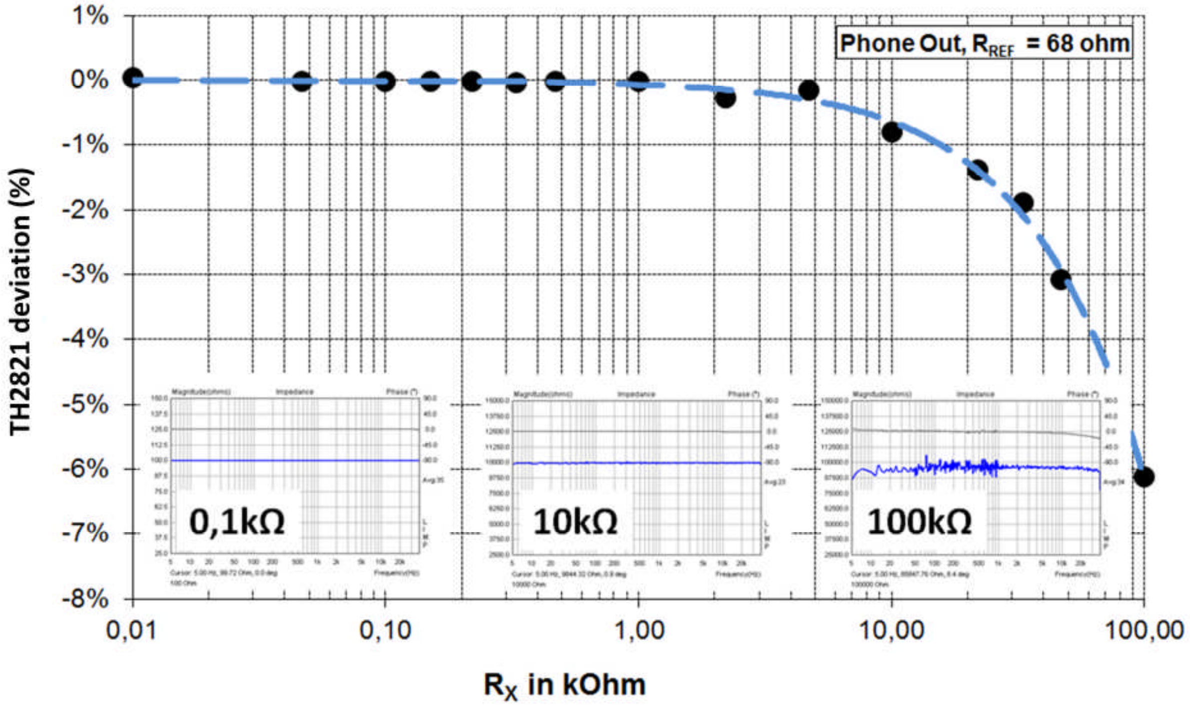


Figure 5.5 Resistances: LIMP vs RLC meter.

6. Accuracy of impedance measurements

The performance limits of LIMP as an RLC meter is determined by the input impedance of the soundcard and the measurement setup. Measurements will be optimized if the soundcard has a high input impedance and will work without an upstream voltage divider, because the parallel resistance of the voltage divider in this situation produces interference. The limits of the setup are shown by noisy measurements (e.g. Figure 5.5, right panel, 100 kOhm).

For this reason the ARTA Measurement Box (see ARTA Application Note 1) represents a compromise between accuracy and ease of use. If the resistor values in the application note are used, errors of measurement up to about 100 ohms should be less than 1%.

Note*: If the soundcard has an input impedance > 500 ohms, then the resistor values of the voltage divider (R1 / R2 and R3 / R4) in the Measurement Box can be increased by a factor of 10. Measurement errors up to 1000 ohms should then be less than 1%.*

If the test setup is correct, impedance measurements with LIMP should be subject to errors of less than 1%. If this is not so, one of the following is usually responsible:

1. The sensitivities of the soundcard input channels are different;
2. The input impedance of the soundcard is too low (10–20 kOhm);
3. The cables between the power amplifier and speaker are too long.

These problems can be addressed as follows:

1. Calibration of the sound card (see section 2.2.1).
2. Use of a soundcard with high input impedance (check specification, professional soundcards have input impedances of 1MOhm) or an upstream input buffer.
3. Inductive or capacitive effects can be contributed by excessively long measurement cables. This also applies to terminal or connector resistance.
   a. Use short measurement cables with sufficient cross-section (≥1.5mm2).
   b. If longer measurement cables must be used, place the reference resistor as close to the speaker terminal as possible.
   c. Ensure secure connections. Use good quality connectors and terminals (see note).

Note*: test leads as shown on the right are often a source of error in measurements on loudspeakers. Because the cables are often just clamped at the crocodile clips they introduce "variable contact resistance". This does not help with reproducibility of measurements. If leads of this type are used, connections should be resoldered and checked.*

7. References

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