

ELECTRICAL IMPEDANCE MEASUREMENTS WITH CLIO 11

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INTRODUCTION

In this document we will address the several possible modes and methods available in CLIO 11 to measure Electrical Impedance and derived measurements such as those of Inductors and Capacitors in the LCR Meter.

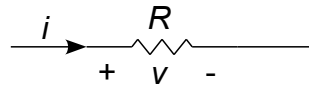
The special case of Loudspeaker Impedance, with its non ideal behavior, will also be addressed together with effects on Thiele & Small parameters estimation.

THEORY AND DEFINITIONS

The electrical impedance is an extension of the concept of electrical resistance to AC circuits. It is well known that the current i which flows through a resistance R is directly proportional to the voltage potential v across resistor terminals, as represented by the Ohm's Law:

$$v = R \cdot i$$

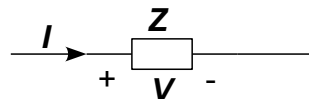
Where R , v and i are scalar quantities.



In a similar fashion, electrical impedance \mathbf{Z} is a complex quantity which describes not only the relative amplitudes of the voltage and current, but also the relative phases. The Ohm's Law becomes:

$$\mathbf{V} = \mathbf{Z} \cdot \mathbf{I}$$

Where the \mathbf{Z} , \mathbf{V} and \mathbf{I} are now complex quantities.



The complex number \mathbf{Z} can be wrote in cartesian:

$$\mathbf{Z} = R + jX$$

or polar form:

$$\mathbf{Z} = |\mathbf{Z}| e^{j \arg(\mathbf{Z})}$$

Following above definitions frequency dependance of the Impedance $\mathbf{Z}(\omega)$ is obviously obtained as a ratio between two Frequency Responses.

A Frequency Response of a system can be properly defined only if the system belongs to the class of LTI (Linear and Time Invariant) systems. This, therefore, applies also to Impedance. Unfortunately Loudspeakers do not meet these requirements completely.

IMPEDANCE MEASUREMENTS BASICS

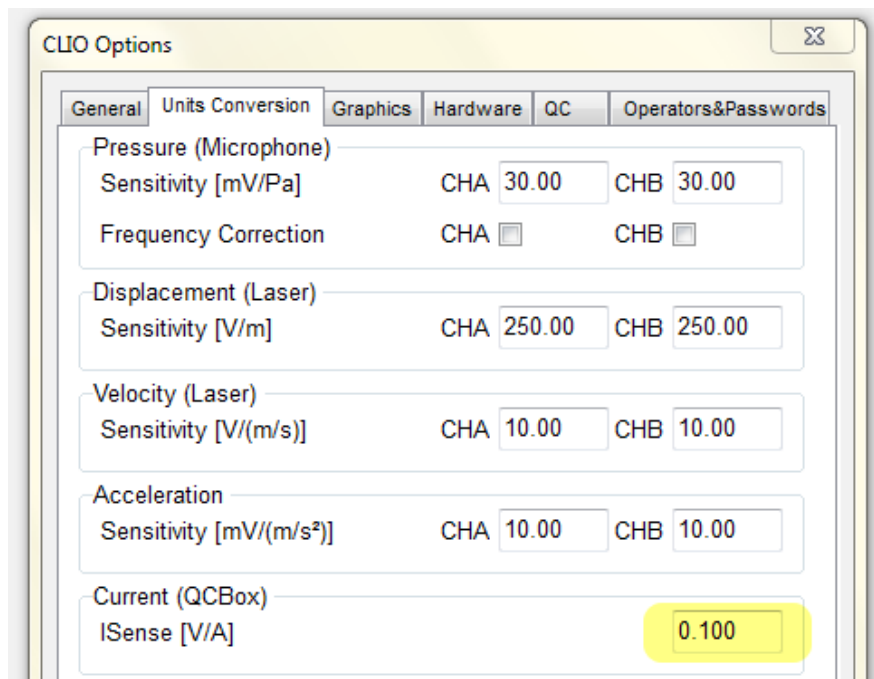
The Impedance measurement is by itself indirect; the impedance value is derived from a voltage and a current measurements.

According to the Ohm's Law:

$$\mathbf{Z}_{(\omega)} = \frac{\mathbf{V}_{(\omega)}}{\mathbf{I}_{(\omega)}}$$

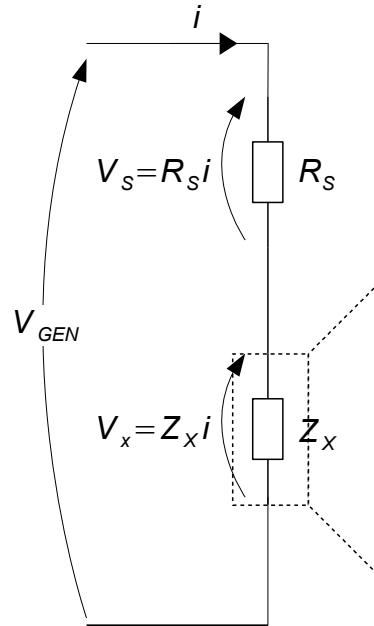
The CLIO hardware, directly, is able to measure Voltage only and has two measuring input channels.

In order to measure currents a proper current to voltage transducer needs to be used and the CLIO 11 software should be instructed with the correct conversion factor.



The most diffuse current-to-voltage transducers for measuring loudspeaker impedance are shunt resistors and hall effect transducers.

In case of a shunt resistor, the simplest choice, the test circuit becomes:



The needed quantities to estimate the DUT impedance are \mathbf{V}_x and \mathbf{I}_x , and there are several ways to collect the data. Two of the three voltages must be measured to solve the above net since:

$$\mathbf{V}_{GEN} = \mathbf{V}_S + \mathbf{V}_x$$

Once \mathbf{V}_S is measured or solved using the above equation, current can be estimated from $\mathbf{I}_x = \frac{\mathbf{V}_S}{R_S}$.

But this does not mean that the voltage and the current must be estimated at the same time, even though this is possible, one of the two can be known in advance or measured not concurrently.

If the value of the shunt resistor R_S is much less than the magnitude of $|\mathbf{Z}_x|$ the voltage $\mathbf{V}_x \approx \mathbf{V}_{GEN}$, then the measuring method is called "constant voltage", since the voltage on the device under test is barely modified by the presence of the shunt resistor.

If the value of the shunt resistor R_S is much greater than the magnitude of $|\mathbf{Z}_x|$ the current flowing in the branch is not affected by the device under test $\mathbf{I}_x \approx \frac{\mathbf{V}_{GEN}}{R_S}$. Then the method is called "constant current".

Each method has its pros and cons, which are described in depth in the technical literature¹. The constant voltage and constant current methods are the legacy of the era when there were available only analog instruments, such as needle voltmeters. In those days it was trivial to generate a sinusoid with a given voltage (10 V for example), while measuring current across a relatively high sensing resistor (say 10 kΩ). In this way one could directly read Ohms on the voltmeter (set in mV) greatly simplifying the acquisition process, which had to be iterated for

1 A detailed description is available in Joseph D'Appolito, "Testing Loudspeakers", Audio Amateur Pubns, 1998

every frequency of interest.

The CLIO 11 software can take advantage of the following CLIO fw-01 hardware features:

- Output voltage is known
- Output impedance is known (330+330 Ohm)
- Input connections are balanced
- Software controlled channel in-out loopback

and also of the following CLIO QCBox model V Amplifier and Switch Box features:

- Precision current sensing resistor on the power output
- Amplifier gain is known

IMPEDANCE MEASUREMENT METHODS AND ANALYSIS MODES

In CLIO 11 there are **three methods** to measure the electrical impedance:

1. Internal Mode
2. Two channels mode (V,I)
3. QCBox Isense

And there are **two analysis modes** to measure voltage and/or current and to get the $Z(\omega)$ as a function of frequency:

1. MLS or LogChirp
2. Sinusoidal analysis

You will find specific information on how to use both modes in the relative chapters of the User's Manual.

In the following examples we will use Sinusoidal to perform Impedance Measurements. Differences, pros and cons between the two analysis modes will be addressed later in this document.

In addition to these, CLIO 11 features a **quick LCR meter** function inside the Multimeter menu which we will show shortly. Here is a summary of impedance measurement methods and modes available in CLIO 11.

Method/Mode	Sinusoidal	MLS or LogChirp	LCR Meter
Internal	✓	✓	✓
Two Channels (V,I)	✓		
QCBox Isense	✓	✓	

Since the available possibilities are manifold, it is advisable to proceed step by step, starting from the simplest: Internal Mode.

INTERNAL MODE

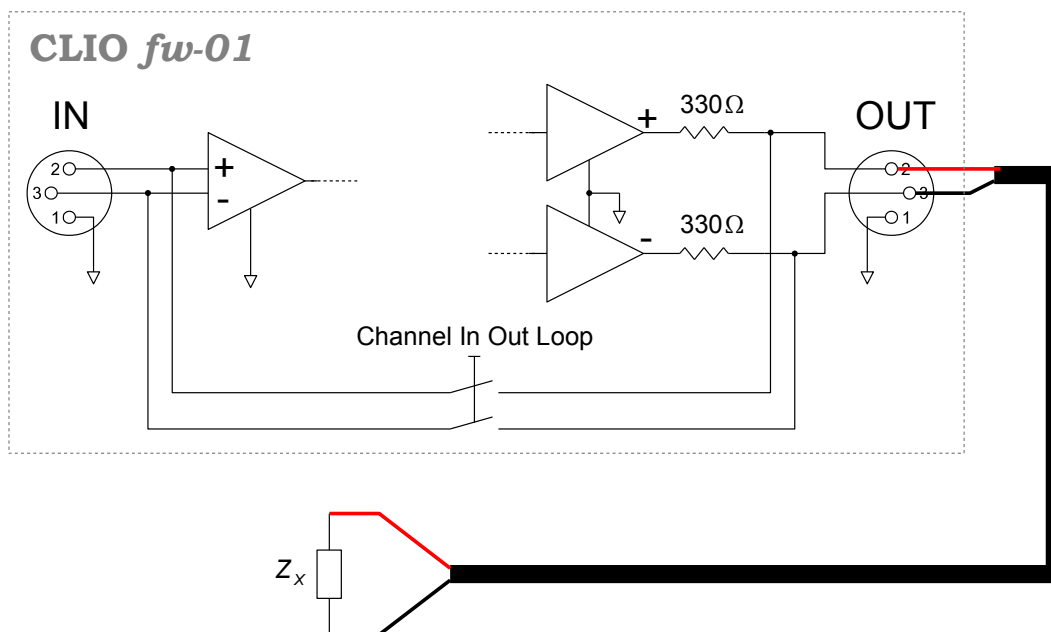
CLIO is able to measure impedance with a single channel and using the XLR F to Alligators cable supplied with the system. The cable connects the pin 2 of the XLR-F connector to the red clip and the pin 3 to the black clip.



In this case, the simplest and the one Users should start from, the software assumes that both unloaded output level and output impedance are known, which, in fact, is the case.

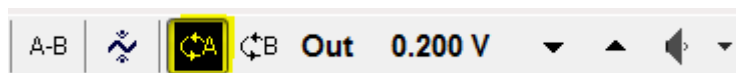
The first one (output Level) is stored during the calibration process. The second is determined by the precision resistors in the output path (660 Ohm 0.1%). We call this method Internal Mode.

Here is a simplified schematic of a CLIO fw-01 hardware balanced input and output channels:



Whatever you are using the LCR Option of the Multi Meter, the Sinusoidal Menu (preferred for impedance) or MIs&LogChirp Menu, there are three set to be changed before you proceed.

First ensure the loop button of the selected channel is down.



This shorts the output (and the device to be measured terminals) to the input. Referring to above CLIO fw-01 schematic, Voltage generated at unloaded output

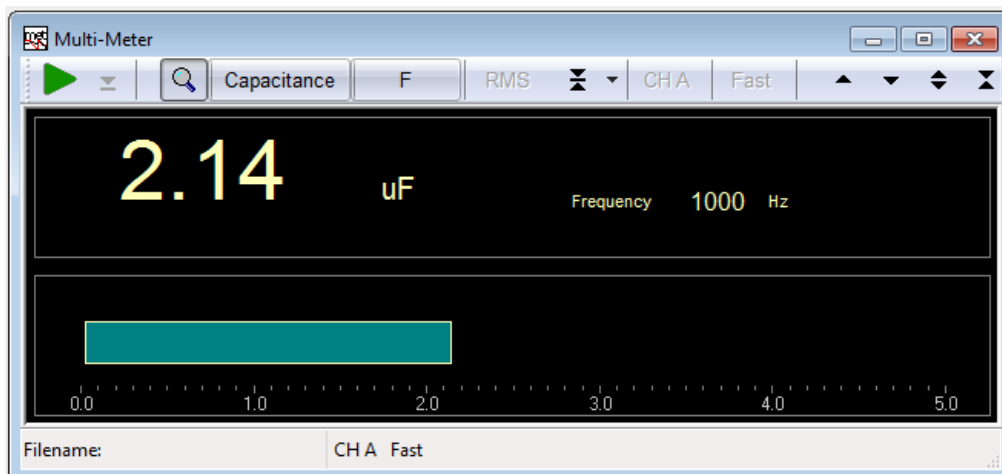
V_{GEN} is known from Calibration, R_{OUT} is known from specs, V_{OUT} is measured and Impedance calculated as:

$$Z_x = \frac{\frac{V_{OUT}}{V_{GEN}}}{1 - \frac{V_{OUT}}{V_{GEN}}} \cdot 660$$

As first check that everything is working, a resistor and a capacitor should be measured, using the **LCR Meter** function of the CLIO Multi-meter menu.

When either Resistance, Capacitance or Inductance is selected as main parameter to be measured, the Multi-meter enters what is called **LCR Meter** state. The **LCR Meter** is a particular operating mode of the Multi-meter that gives you the possibility of measuring inductors, capacitors and resistors.

The **LCR Meter** takes control of the generator² and, when the measurement is started, outputs a series of sinusoids of variable frequency in order to find the best frequency to carry out the measurement. The output frequency can be displayed (with the magnifier button) together with the measured parameter.

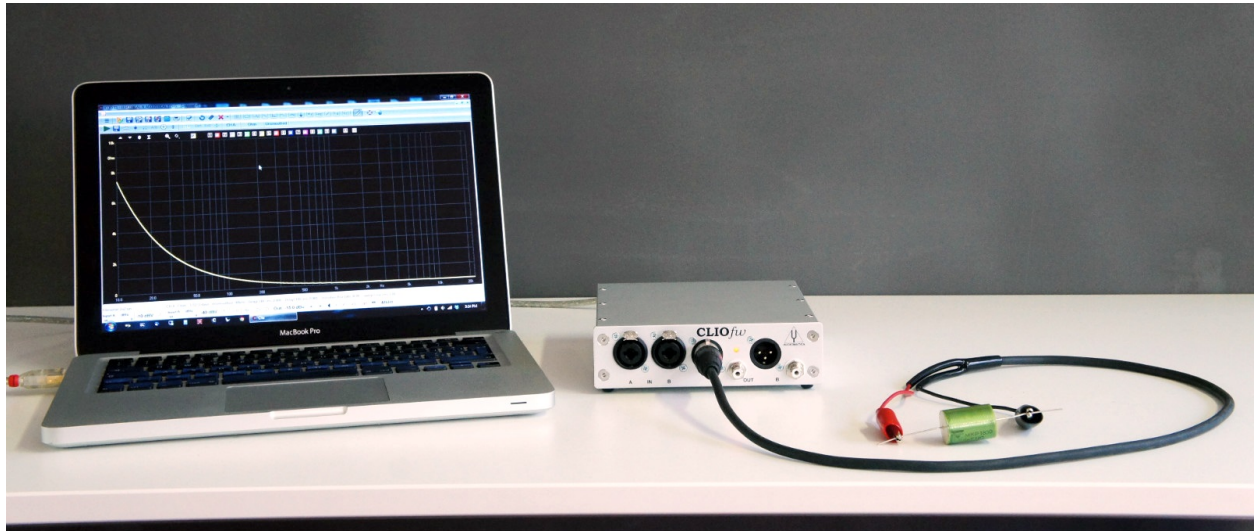


What is displayed above is an Impedance derived measure of a capacitor taken at 1kHz. Frequency is chosen by the software. Only Imaginary part is considered in calculating the final value. With low Q devices this can make a difference vs a magnitude only approach. An Impedance curve should solve any doubts.

² The LCR Meter operates only on channel A.

ELECTRICAL IMPEDANCE MEASUREMENTS WITH CLIO 11

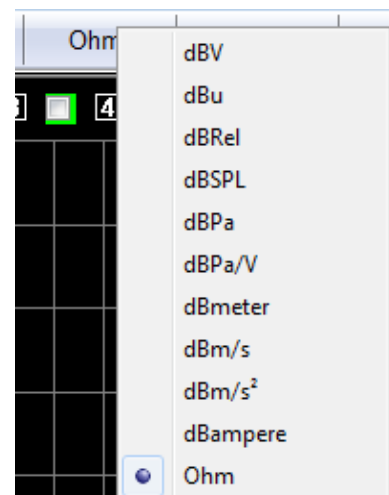
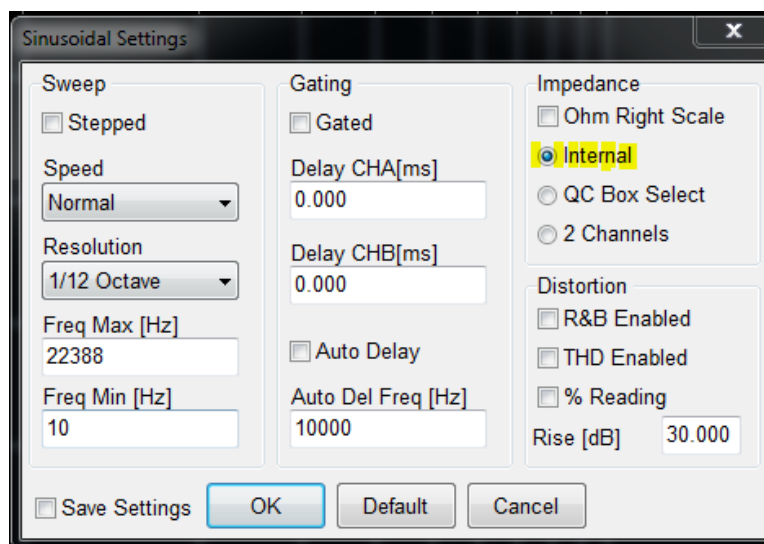
The setup used is shown in the following picture:



Proceeding without changing connections the Sinusoidal Menu can be opened.

The second thing that has to be set is Internal Impedance Mode within the Sinusoidal Settings.

Finally set Ohm as measure unit and execute a Sinusoidal measurement.

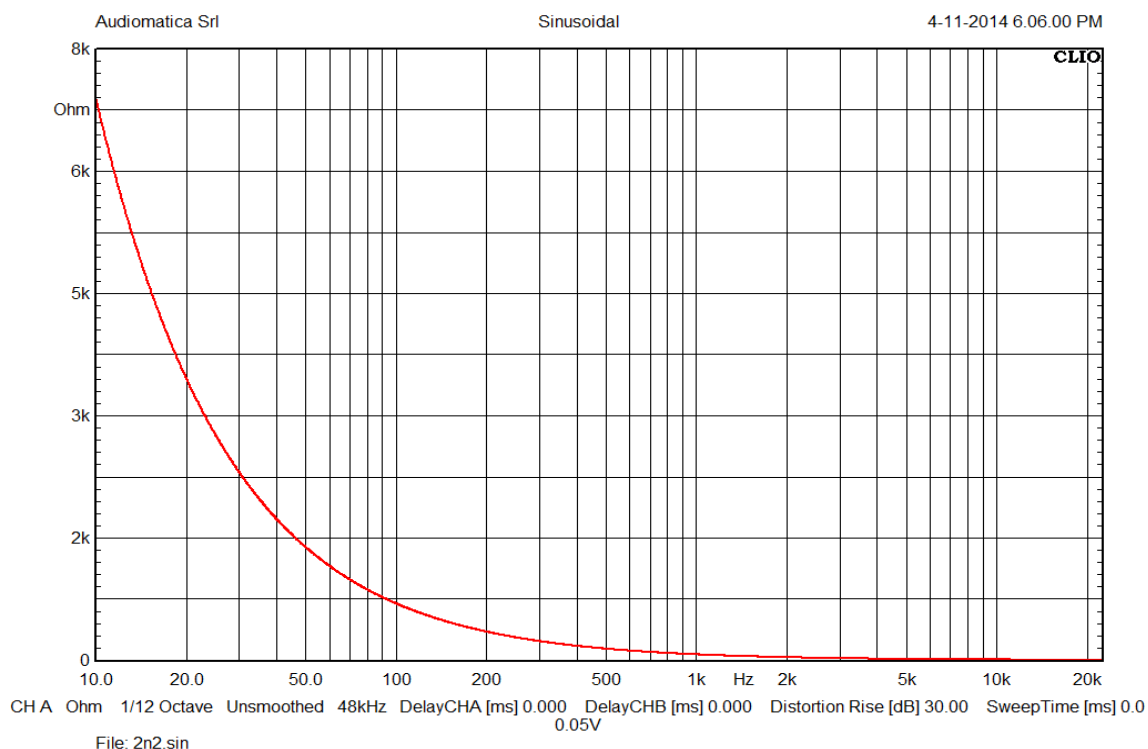


Set the CLIO output level to 1 V, verify that the loop button is still down.

Everything should be ready to perform the first Impedance vs Frequency measurement, just press the Start Measure button.

Depending on what is connected to the alligators you should see a graphics similar to the one below which refers to Impedance from 10-22kHz of a nominal 2.2uF capacitor.

ELECTRICAL IMPEDANCE MEASUREMENTS WITH CLIO 11

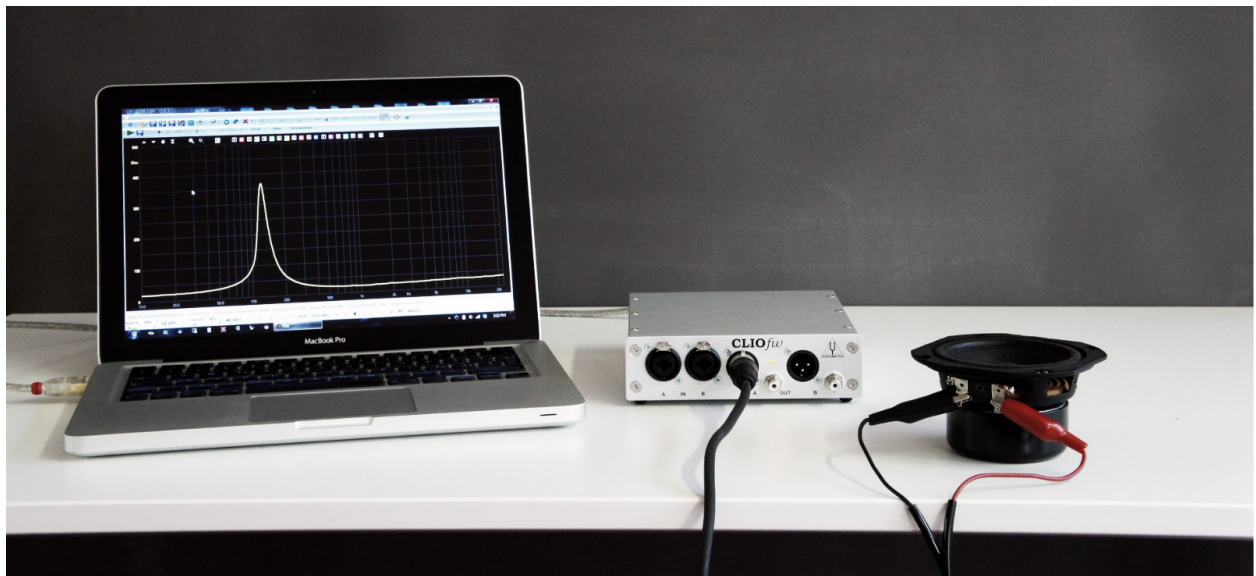


It should be noted that the range of the measured impedance is very large, this calls for a proper setting of the input sensitivity of the CLIO fw-01 box. The lowest Input Full Scale Level (without saturating the input) which maximizes the signal to noise ratio at low frequencies should be selected.

Same can be done using the MLS&LogChirp menu, with similar results. We invite the reader to measure simple components before embarking on measurement of loudspeakers electrical impedance.

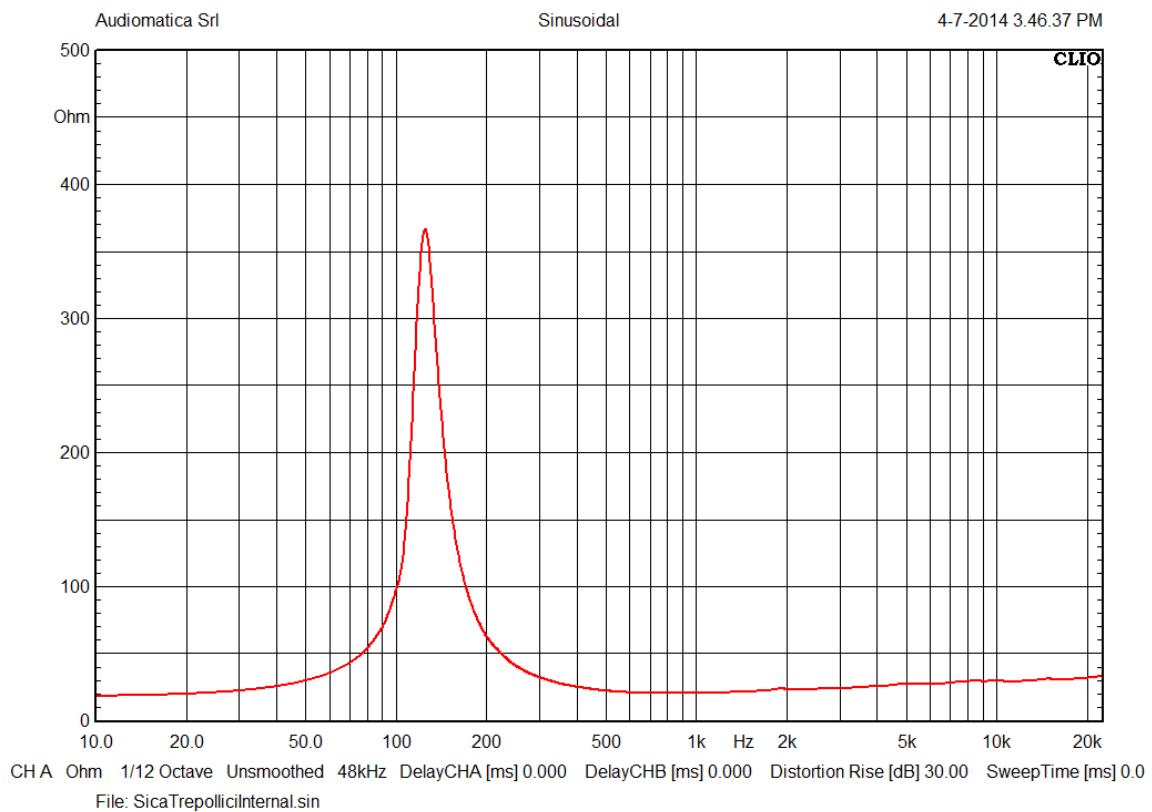
We show here now the measurement of a loudspeaker electrical impedance using Internal Mode and Sinusoidal menu. Some measurement settings should be now taken for granted, the dependence of the impedance curve of these settings will be analyzed later. Here we must again point out that the speaker is a non-linear and not time-invariant device, so the measurement mode and settings are going to influence the result.

We connect the loudspeaker to be tested using the same setup previously used, and we run the Sinusoidal analysis. As output level we can still use the 1 V (0 dBV) value.



Please take into account that the loudspeaker should be properly mounted on a test jig in order to avoid reflections, vibrations and without obstructing vents. These are all factors that can influence loudspeaker impedance measurements, we will address them in detail later.

Here is the result of our first loudspeaker impedance measurement:

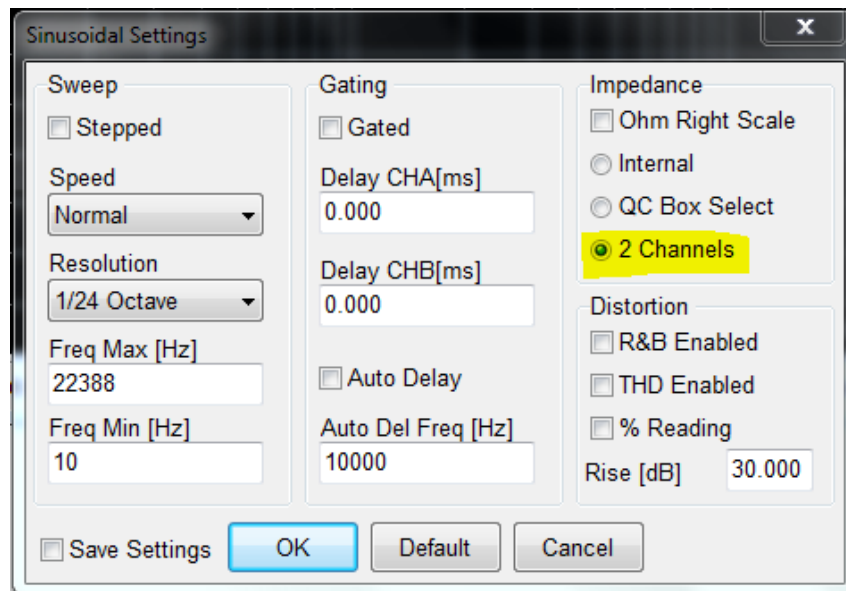


which is the result we were expecting.

TWO CHANNELS MODE (V,I)

Constant Current and Constant Voltage were the standard approaches to measure impedance with a traditional set of instruments. There are no reasons to use them nowadays with CLIO 11, since the Two Channels (V,I) mode supersedes both of them³.

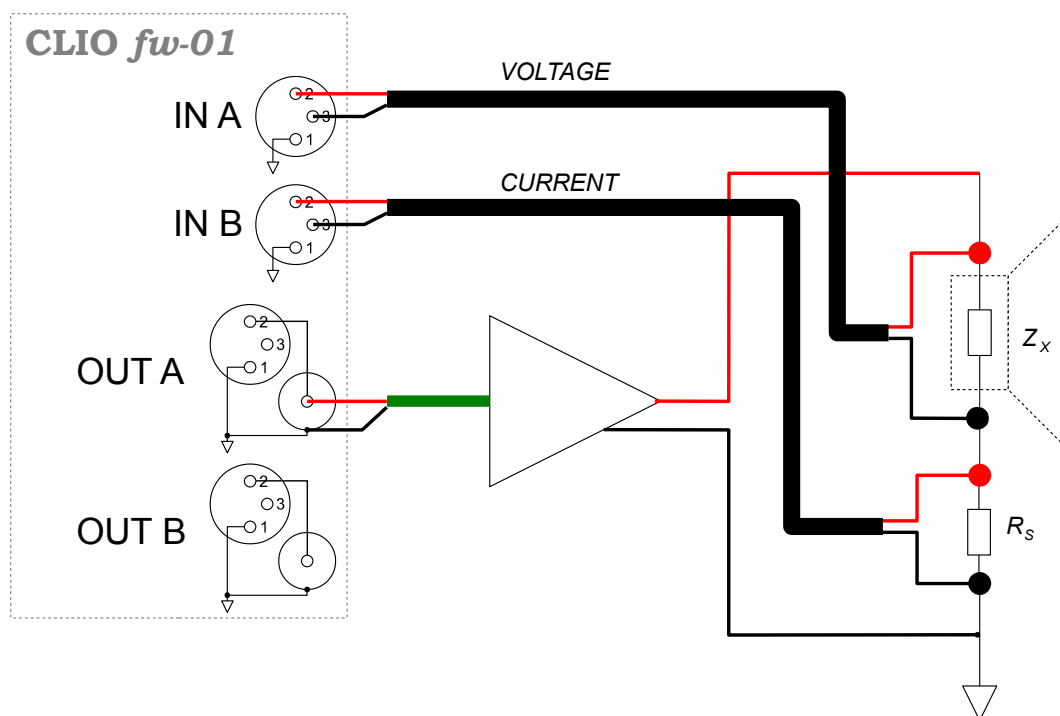
This mode is available under Sinusoidal menu, and can be activated from the Options dialog:



In this mode the CLIO fw-01 should be connected to measure the voltage on input A and the current on input B. As previously stated CLIO fw-01 is only able to read voltages, so current must be read using a proper current-to-voltage transducer.

In the following example we will use an external amplifier and an external sensing resistor.

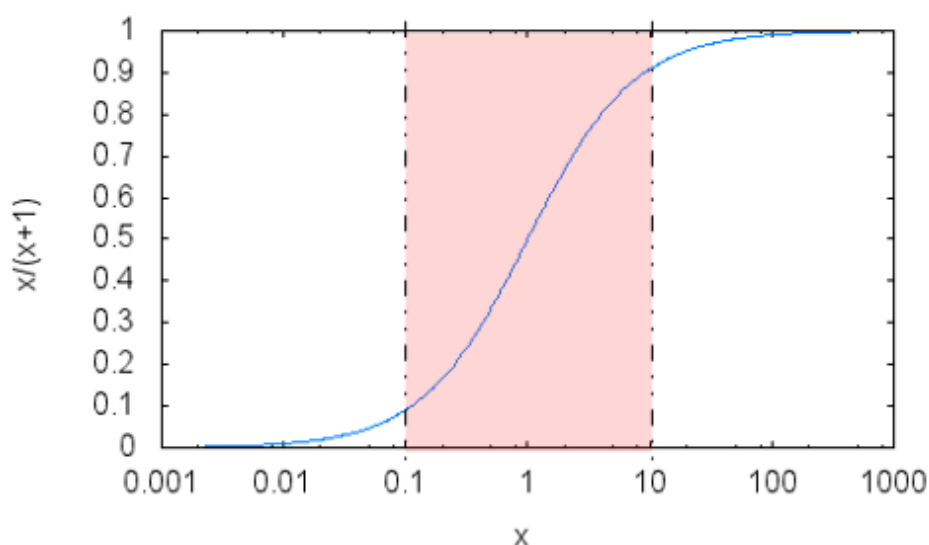
³ Both Constant Current and Constant Voltage methods require two measurements to be taken one after the other, changing connections in between. CLIO, by means of its processing tools, can speed things up a lot but the whole procedure remains quite complicated and there is no reason to use it.



Selecting an external resistor of proper value, is it possible to have situations similar to either constant voltage (low R_s values) and constant current (high R_s values). But in this case we are free from the constraints of the classical modes and the R_s value can be selected to get the best signal to noise ratio for the measurement.

With reference to the test circuit reported at page 3, the ratio of the magnitude of voltage at the DUT and at the generator $\frac{|V_x|}{|V_{GEN}|}$ as a function of the ratio of the impedance $\frac{|Z_x|}{R_s}$ has the form:

$$y = \frac{x}{1+x}$$



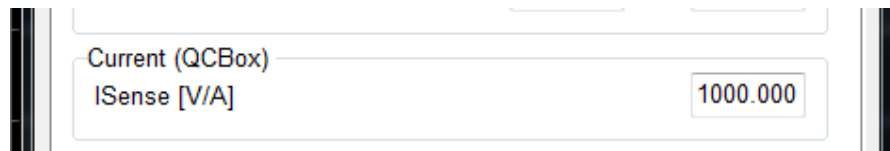
The maximum sensitivity is at the point $x=1$, where measured voltage is half of

the generated voltage and $|\mathbf{Z}_x| = R_s$.

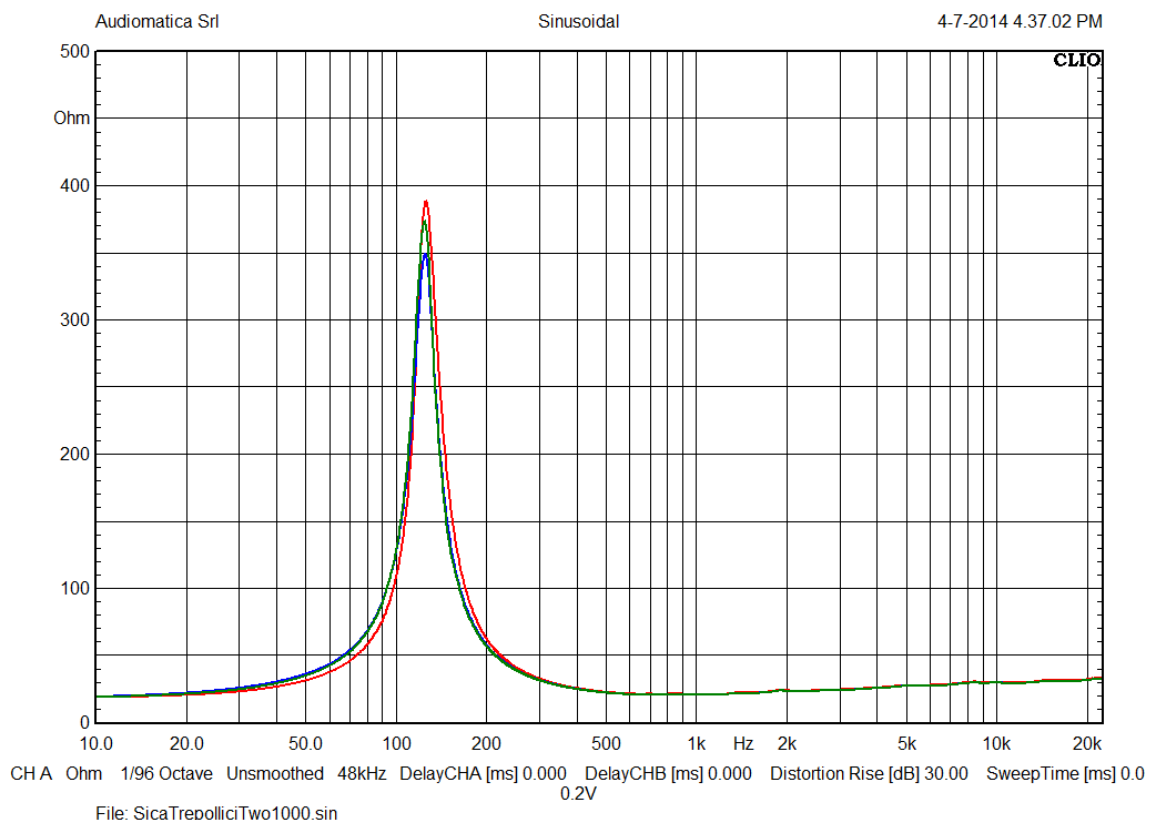
We can see from the graphic above that a meaningful range for the R_s sensing resistor lies between $0.1 < x < 10$, which means a value of R_s not less than ten times and not over ten times the magnitude of $|\mathbf{Z}_x|$.

We should also instruct CLIO software of the transduction coefficient of the shunt resistor (which is its resistance value, this can be measured with CLIO 11 with internal mode, with a precision DMM or assumed to be its nominal value).

As an example if $R_s = 1\text{ k}\Omega$ then the CLIO settings should be changed accordingly:



Following is an example of measurement results of an high Rdc loudspeaker (nominal 24 ohm) with a sharp resonance peak, this is the kind of device which puts constant voltage measurement modes, as the Isense QC Box mode, into trouble. At the loudspeaker resonance peak the current has a minimum that corresponds to a minimum into the sensing voltage, which can easily fall into the measurement noise.

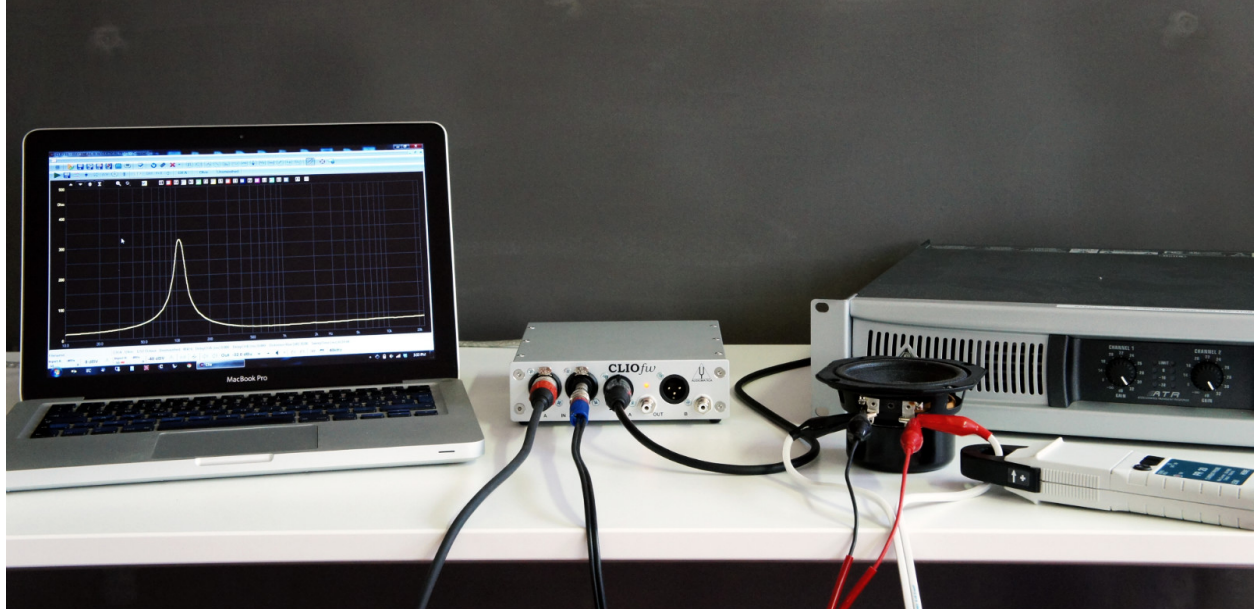


The blue curve is measured with a 1 ohm resistor, the green curve with a 10 ohm resistor and the red curve with a 1 kohm resistor. It can be seen that we moved from constant voltage mode towards constant current.

ELECTRICAL IMPEDANCE MEASUREMENTS WITH CLIO 11

Another possibility to measure with the two channels mode is to use an Hall effect transducer for the current reading. These are electromagnetically coupled devices which are not altering the signal path and also allows to avoid to disconnect the device under test from the amplifier in order to perform the test.

By avoiding the sensing resistor it is also possible, using a current clamp, to drive the loudspeaker at very high driving levels.



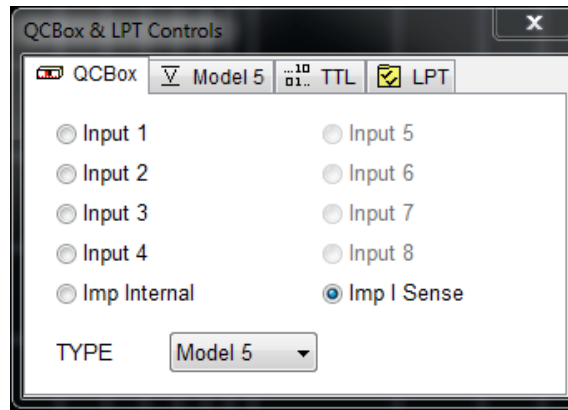
The proper conversion factor of the current clamp should be inserted into the CLIO settings.

QCBOX ISENSE

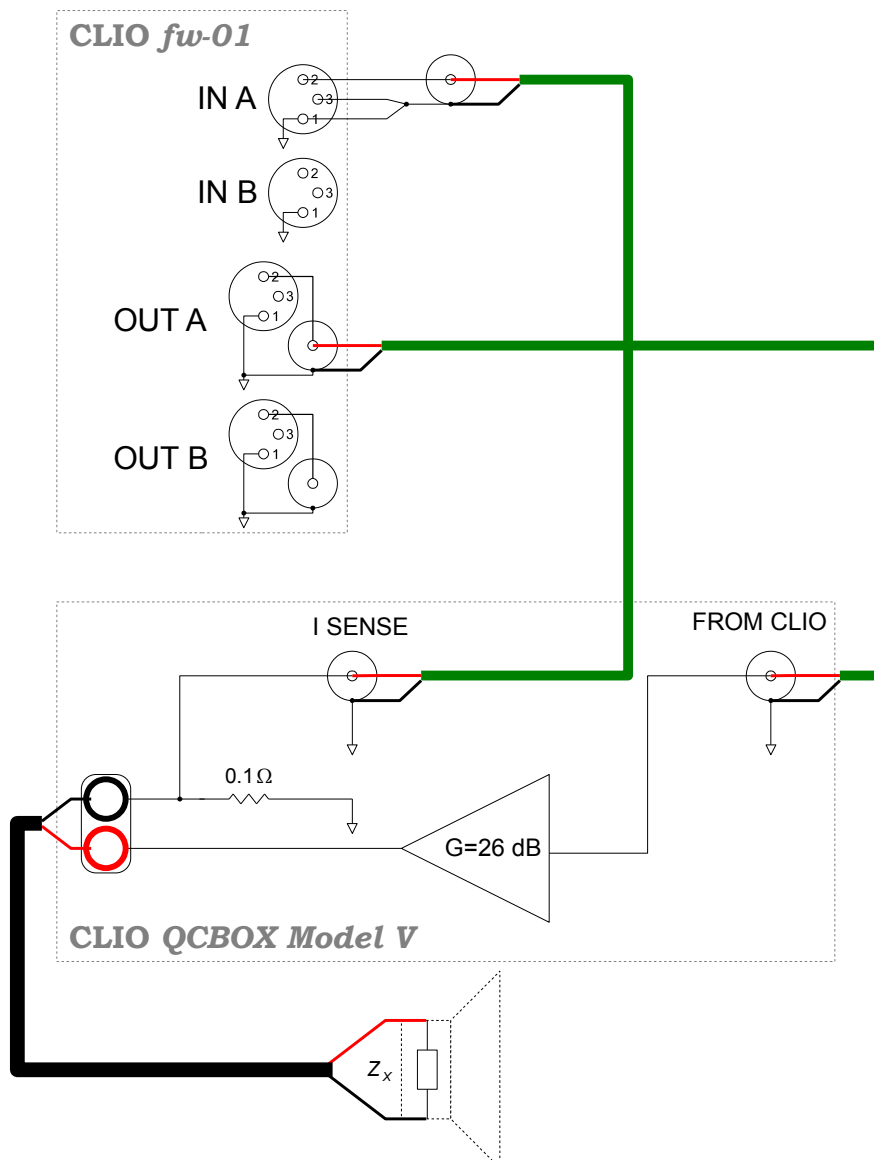
This requires Audiomatica CLIO QCBox Amplifier and Switch Box model 5. It is a simplified Constant Voltage method.

Simplification arises as both device gain and sensing resistor ($0.1\ \Omega$) are known.

The following figure shows the CLIOQC Software Control Dialog Box. I Sense should be selected.

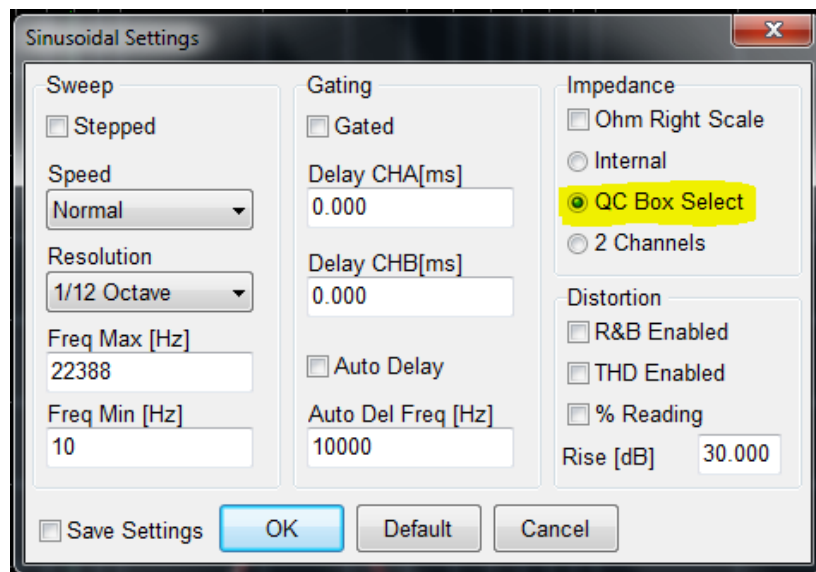


The next figure reports the required connections:



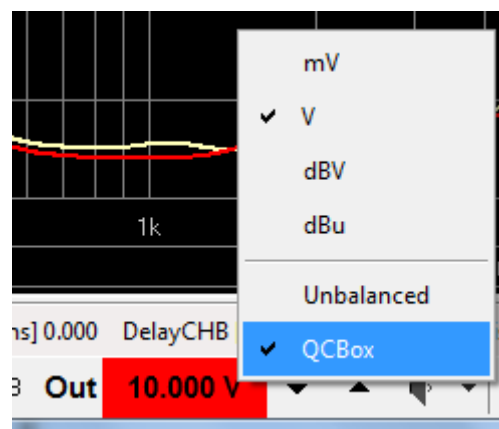
ELECTRICAL IMPEDANCE MEASUREMENTS WITH CLIO 11

Before proceeding, whether in MLS or Sinusoidal, remember to go into the Settings Dialog and select I Sense under Impedance. Here is shown the Sinusoidal Settings dialog:



The CLIOQC Model 5 Amplifier gain is 26 dB (x20). As the output impedance is close to zero, no further attenuation occurs once the speaker is connected⁴.

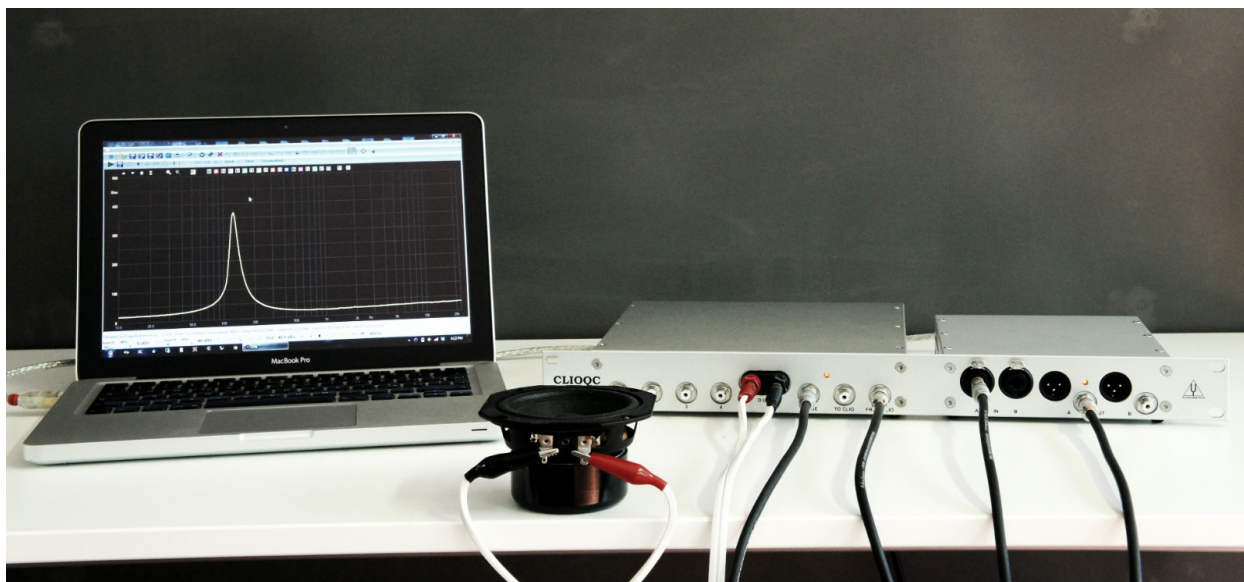
CLIO 11 generator has the very useful feature to set directly the voltage at the QC Box output⁵. This is activated by right click on the generator level and selecting QC Box from the choices. The generator output level background becomes red to reflect this.



The CLIO fw-01 output should be connected to the QC Box (FROM CLIO) input, and the Isense output of the QC Box should be connected to CLIO fw-01 input, as in the previous schematic.

⁴ Amplifier gain and output impedance are precisely measured during production and stored in each QCBox device.

⁵ The CLIO 11 software corrects the output level to match the specific QCBox values.



The device under test can be connected to the QC Box power output using proper AWG wiring of negligible impedance. Cable impedance can be corrected through post-processing.

Once the connections are properly done, and QC Box mode selected into the measurement method settings, the measurement can be simply performed pressing the go button.

The QC Box Isense mode is our preferred choice in production lines quality control, thanks to its simple connections and reliable results. The QC Box Isense mode it is also very valuable in R&D applications where repeatability is a must.

IMPEDANCE MEASUREMENT ANALYSIS MODES

As stated before, alongside the simplified multi-meter mode, there are two measurement analysis available in CLIO 11 to get a voltage versus frequency reading:

- MLS & LogChirp
- Sinusoidal analysis

The MLS & LogChirp mode uses either an MLS sequence or a Logarithmic sweep of a given length (which is a power of 2) to get the impulse response of the device under test. In case of Linear and Time Invariant systems (LTI) the impulse response can be transformed in its dual: the complex frequency response.

It should be noted that while the MLS signal has a white spectrum, the LogChirp has a pink one. This property of the LogChirp could be very useful in order to improve the signal to noise ratio.

The Sinusoidal analysis uses a series of sinusoidal tones (which can be continuously generated or stepped) and DFT analysis to get the frequency response. The Sinusoidal analysis has the best signal to noise ratio of the three analysis modes mentioned.

When measuring Impedances, Sinusoidal is our preferred choice. If used, MLS & LogChirp can lead out to several problems. The inexperienced user might ask why the MLS & LogChirp Menu has impedance measuring capability at all. The answer is that MLS & LogChirp yields accurate Impedance Measurements. It is, however, a method subject to errors and/or measuring set-up problems that users should know and avoid. Furthermore MLS & LogChirp has advantages over

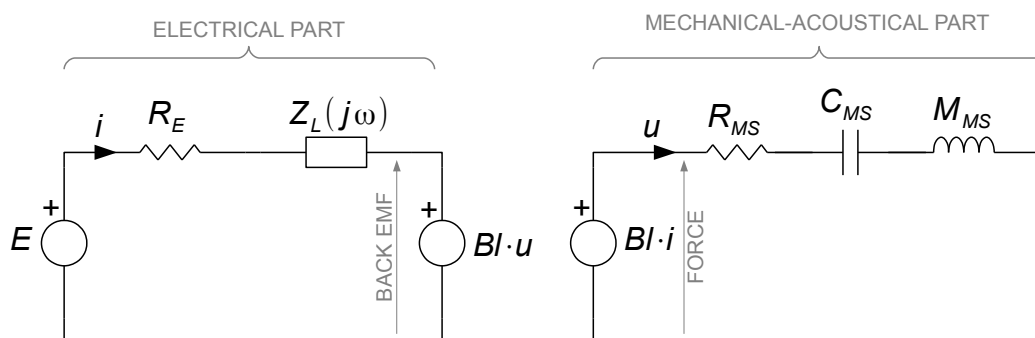
Sinusoidal. The most evident is execution time which is significantly better, even using big sizes, which, by the way, is always advisable. The measurement is extended below 10Hz, while Sinusoidal stops at 10Hz. Its high sensitivity to even weak non-linearity can be used to reveal even small rub & buzz problems, directly from the impedance measure. We advise you to use Sinusoidal measurement techniques initially until you become more experienced with CLIO. After which everyone will be able to form an opinion based on personal experience.

On the other side Sinusoidal has the ulterior advantage to carry out dual channels measurements, to catch, in a single sweep, impedance and displacement, or impedance and acoustic pressure.

MEASURING LOUSPEAKER IMPEDANCES: ADVICES AND CAVEATS

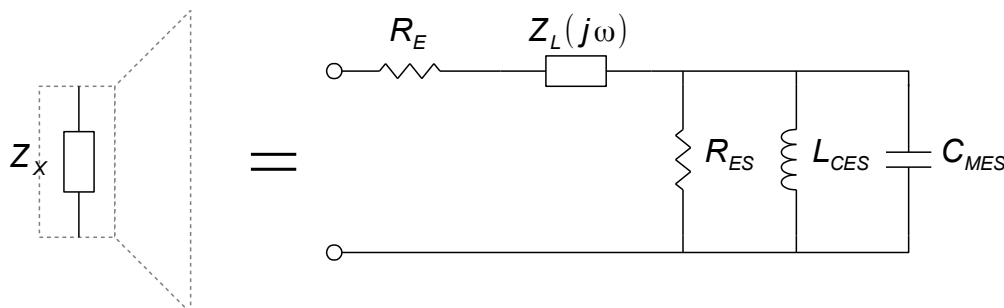
A Frequency Response of a system can be properly defined only if the system belongs to the class of LTI (Linear and Time Invariant) systems. This, therefore, applies also to Impedance. Unfortunately Loudspeakers do not meet these requirements completely.

Under small-signal assumption a moving coil loudspeaker can be modeled with an equivalent lumped parameters electrical-mechanical-acoustical system.



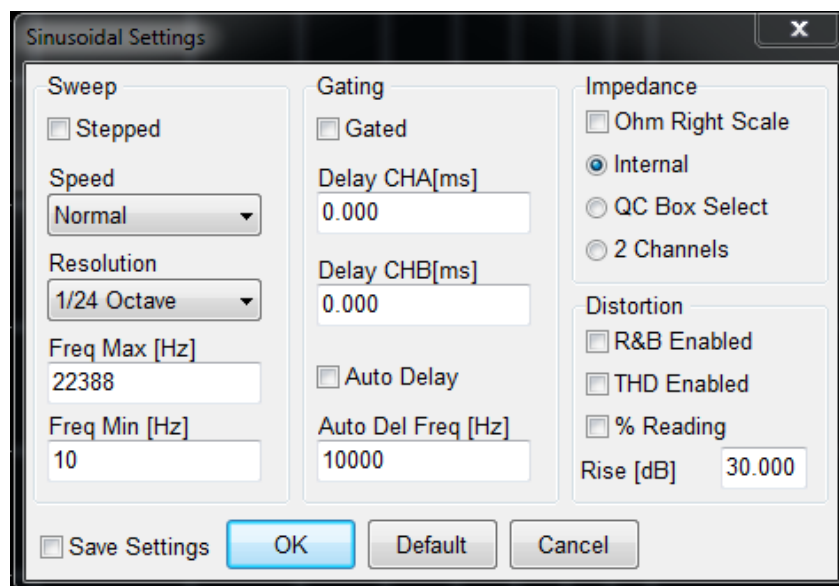
The mechanical-acoustical part takes into account the fact that the cone is moving due to the force provided by the current flowing into the coil immersed in a magnetic field. Damping, inertia and losses are due to cone and suspensions mass, spring effect and compliance. The electrical part models the coil itself, where the movement is translated into a back electromotive force.

We will not get into the details of the small-signal moving coil loudspeaker model, here we only would like to point out that, if seen from the electrical terminals, a loudspeaker presents an electrical impedance that can be modeled as the following circuit.



ELECTRICAL IMPEDANCE MEASUREMENTS WITH CLIO 11

We will show here an example of impedance measurement of a 3.5 inch woofer using Sinusoidal and internal mode with the following Settings:



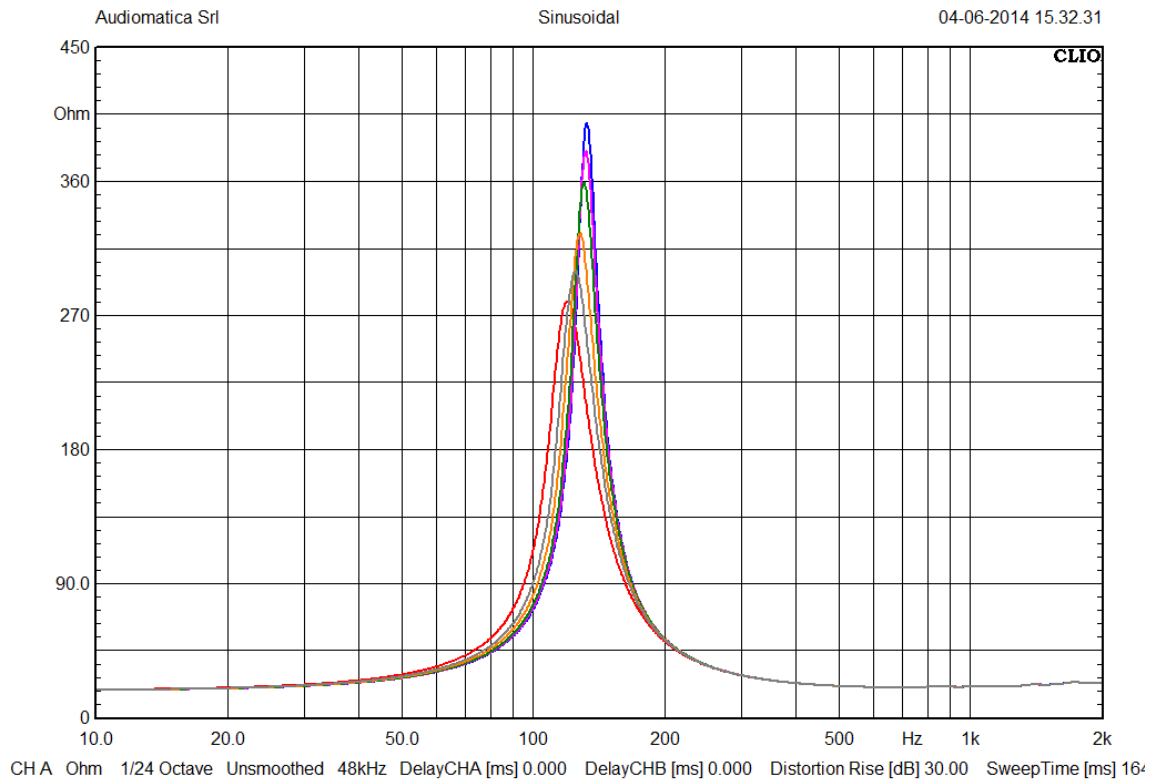
Besides frequency range, which can be changed without side effects, those above are problem free settings for impedance measurements. We will experiment a little, pointing out difficulties that might arise. Let's start with output level, which is a sensitive topic.

SETTING THE RIGHT LEVEL

The simplified model of the electrodynamic loudspeaker we have shown above is seldom applicable. There are several source of non-linearity in a loudspeaker, which start to appear even at low driving levels. The Bl product and C_{MS} are dependent on cone movement, and distortions arise from current flowing into the moving coil.

The six curves of the following figure are taken at 6 different CLIO fw-01 output levels, ranging from -12 dBu to 18 dBu in 6dB steps. The blue curve refers to -12dBu, the red to +18dBu. It can be seen that the impedance peak amplitude and the resonance frequency are decreasing with an increasing driving level.

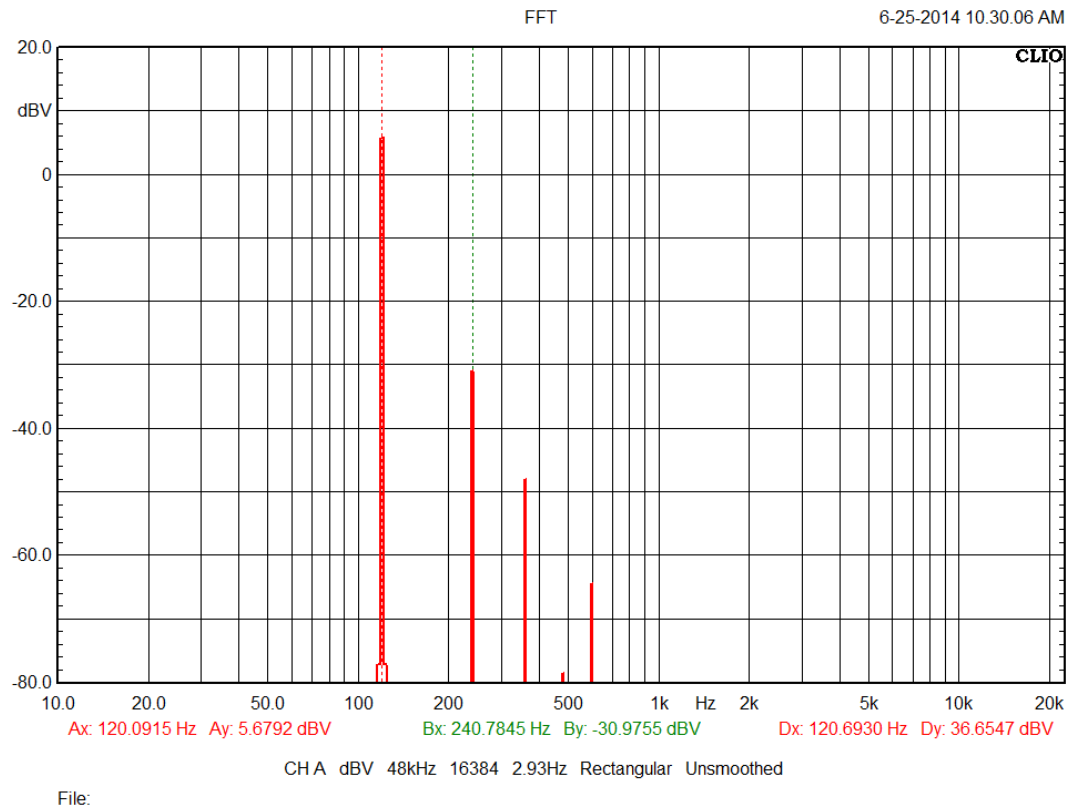
ELECTRICAL IMPEDANCE MEASUREMENTS WITH CLIO 11



It turns out that going from a linear device such a resistor to loudspeakers makes life harder even if more interesting. Deriving the principals T&S Parameters from the five curves yields to following table:

Level	Fs	Qms	Qes	Qts
+18 dBu	119.97	5.028	0.343	0.321
+12 dBu	125.05	5.795	0.368	0.346
+6 dBu	127.90	6.631	0.386	0.365
0 dBu	130.83	7.731	0.405	0.384
-6 dBu	132.31	8.525	0.421	0.401
-12 dBu	132.81	8.994	0.422	0.403

Without changing connections we will use CLIO's FFT and Signal Generator to evaluate the distortion current at resonance at +18 dBu. Following figure shows the spectrum in this condition. The second harmonic is 36 dB lower than the fundamental, which is 1.5% distortion. Even at +18 dBu we are easily in the linear region of the loudspeaker motor. However what we have seen above, clearly states 0 dBu is starting to be the level where more parts are participating to the movement, and therefore the parameters of the linear model of the device are starting to change.

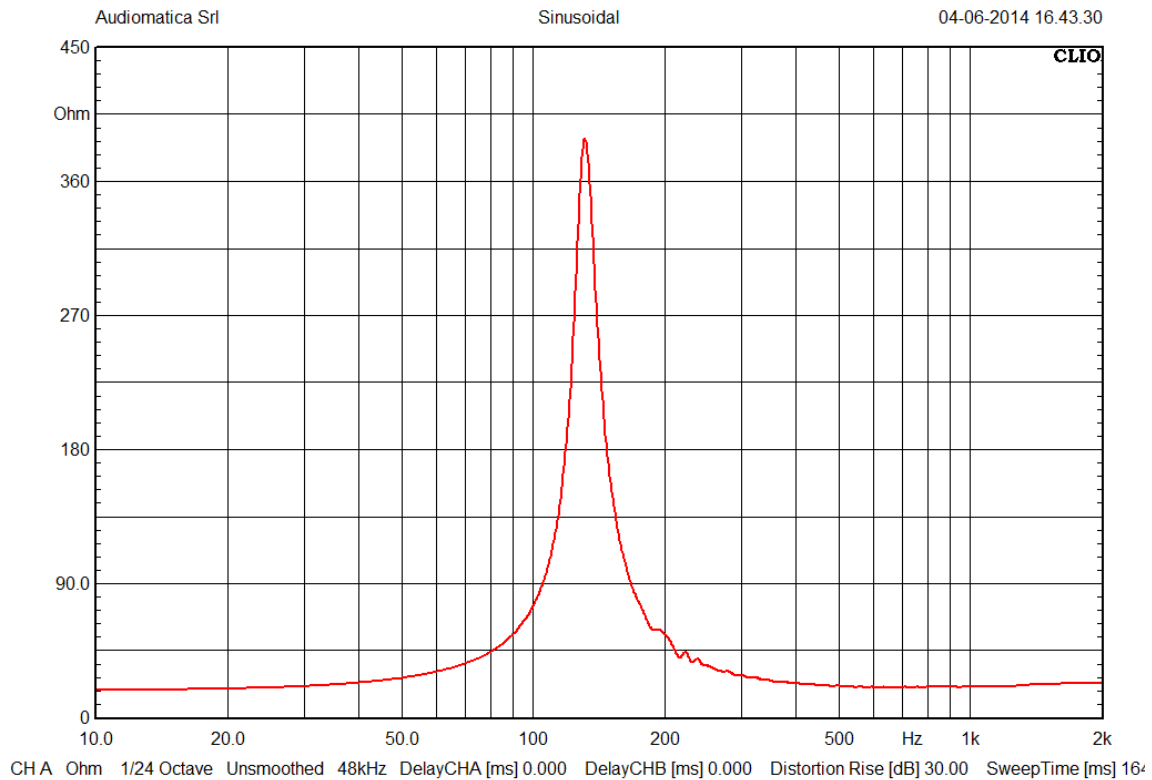


The reader could be tempted to determine the absolute quality of the device by means of this procedure. While he or she may be right, a lot of experience is needed. One important parameter, for reliable comparison among devices, is the value, in VRMS, at the speaker terminals at resonance. It is shown from FFT with CLIO fw-01 output 0 dBu that this value is 0.245 V.

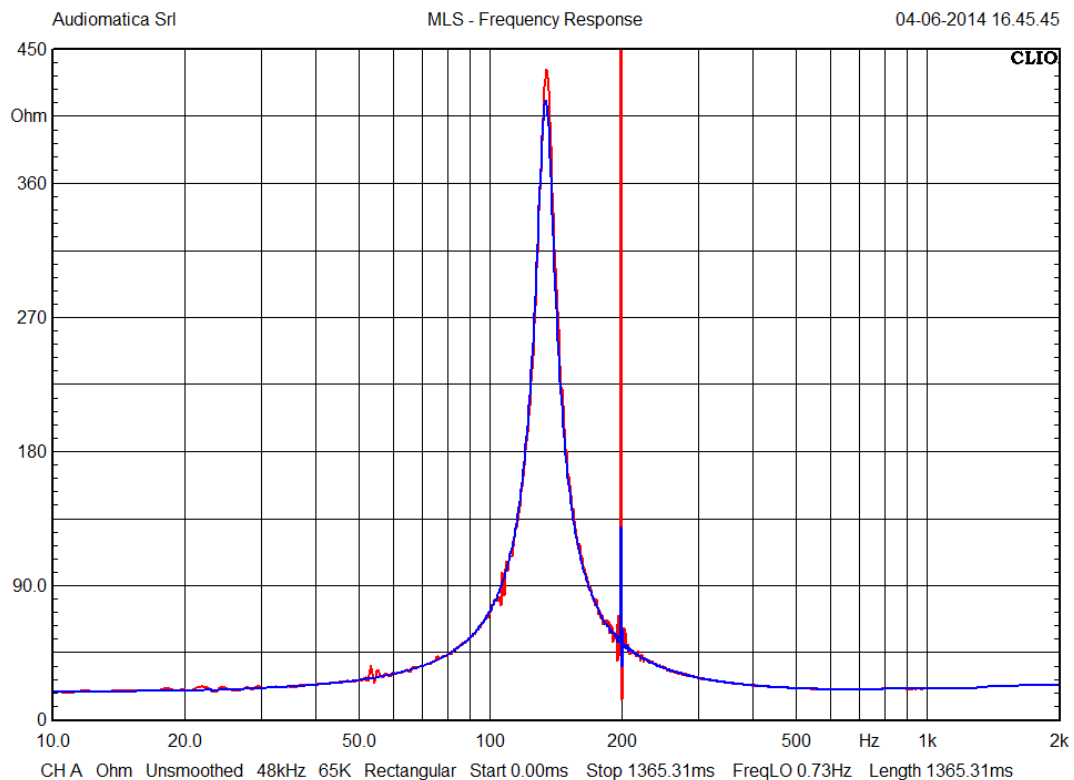
DEALING WITH ENVIRONMENTAL NOISE

The next problem in measuring loudspeaker impedance is noise. Transducers do their job in both directions and noise will appear as voltage exactly where CLIO's input is connected. To evaluate the problem we deliberately produced a disturbance by generating a 200 Hz single tone causing 70 dB SPL at the speaker cone. We took three impedance curves in this condition two with MLS&LogChirp (using either MLS and LogChirp as stimulus) the third with Sinusoidal. All were taken at -6 dBu, a value that gained our favor before. Results are in next figures for Sinusoidal:

ELECTRICAL IMPEDANCE MEASUREMENTS WITH CLIO 11



and for MLS&LogChirp (red curve with MLS stimulus and blue curve with LogChirp stimulus):



This is one reason why we prefer sinusoidal analysis to measure impedance.

DEALING WITH VIBRATIONS

The last enemy we must consider is external vibrations.

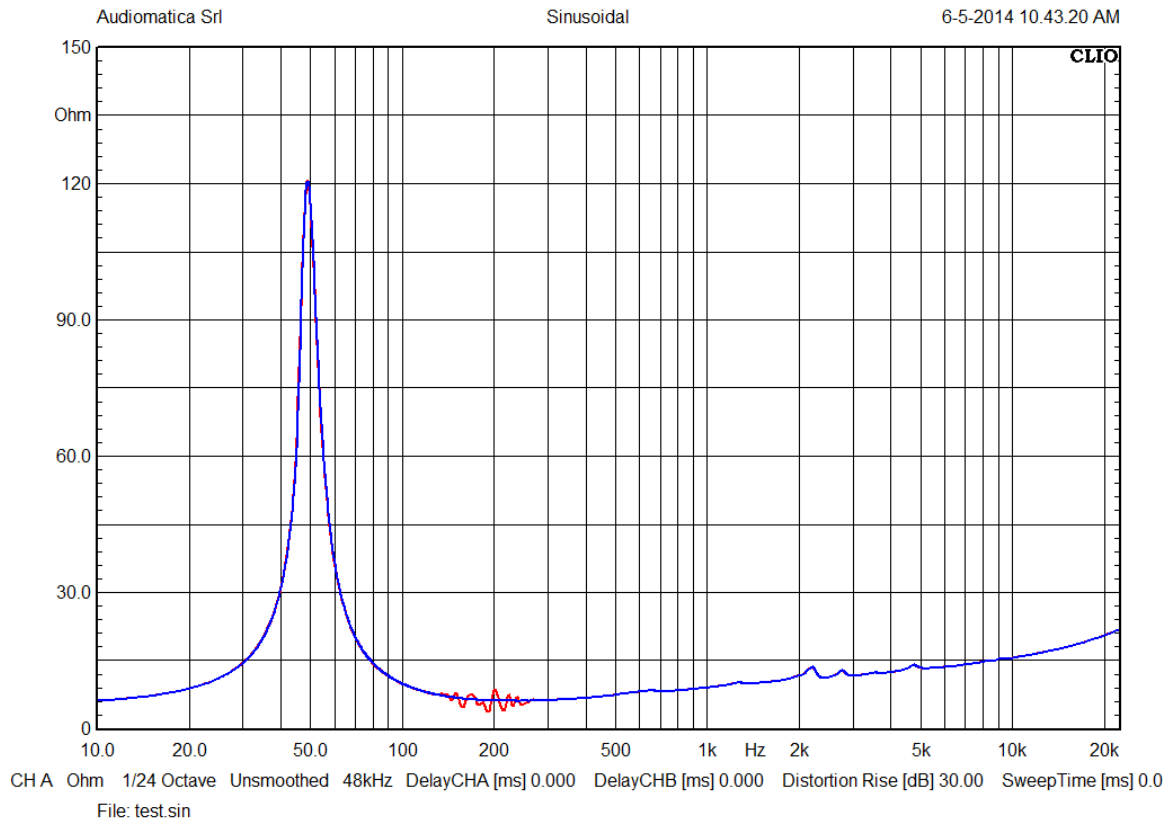


Figure above shows an impedance curve taken with the loudspeaker positioned on a computer table (red curve), on one of those appendages that may be flipped up or down upon needs. This support clearly resonates, excited by the loudspeaker, at around 200 Hz. No matter how good the loudspeaker is fixed to a structure if the structure itself moves then potential problems may become apparent. Usually there is no need to fix anything as long as you are using a stable, non-resonating structure (as measured correctly in the blue curve).

CONCLUSIONS

CLIO 11 is a powerful instrument capable to measure electrical impedance in several methods. Options and measurement menu involved were discussed in detail.