AUDIOMATICA

# AN-024
# APPLICATION NOTE

## MEASURING LOUDSPEAKER IMPEDANCE USING CLIO POCKET

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## INTRODUCTION

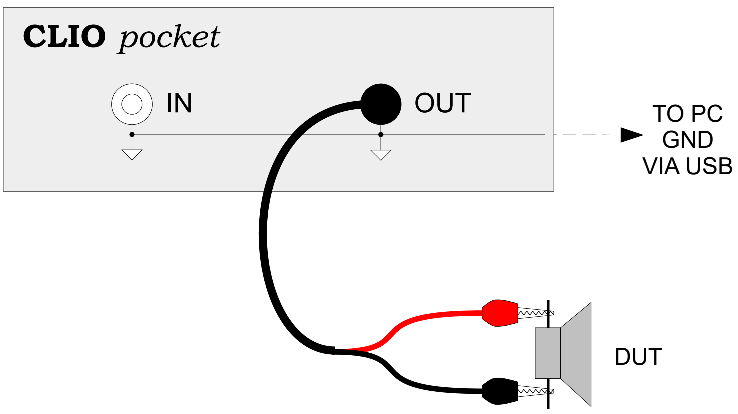
In this application note we will review three different methods to measure the impedance of a loudspeaker with CLIO Pocket: Internal, V/I with shunt resistor, V/I with current probe.

A new time window processing useful for impedance measurements using the LogChirp method is also presented.

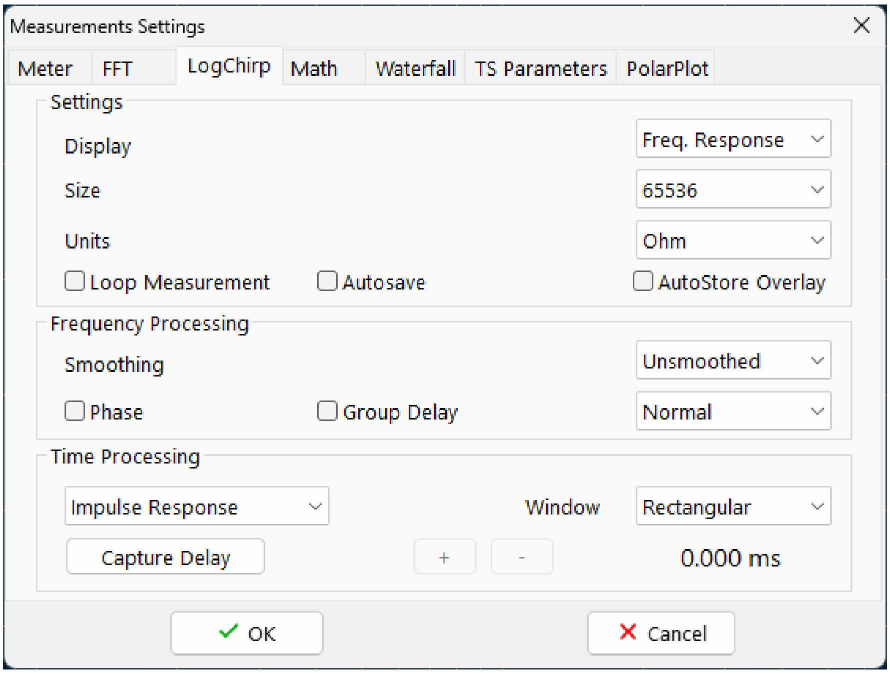
## INTERNAL METHOD

Clio Pocket uses the LogChirp analysis to measure loudspeaker's impedance with the "internal" method. This method leverages the fact that the output voltage and output impedance of the Clio CP-01 box are precisely known, allowing to measure the current flowing through the loudspeaker.

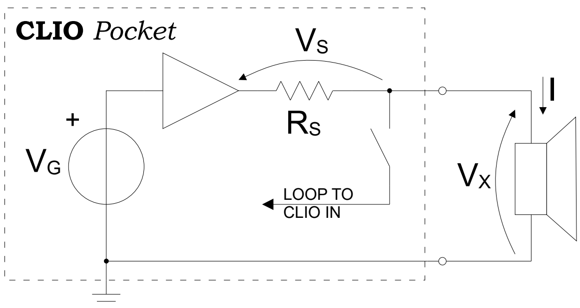
This method is very easy to use. The loudspeaker is connected directly to the Clio CP-01 interface output via the provided RCA-to-alligator clips cable. The software handles the calculations in background, and the result is displayed immediately on screen.



To measure the loudspeaker impedance with the above method and connection, the following LogChirp settings should be used:

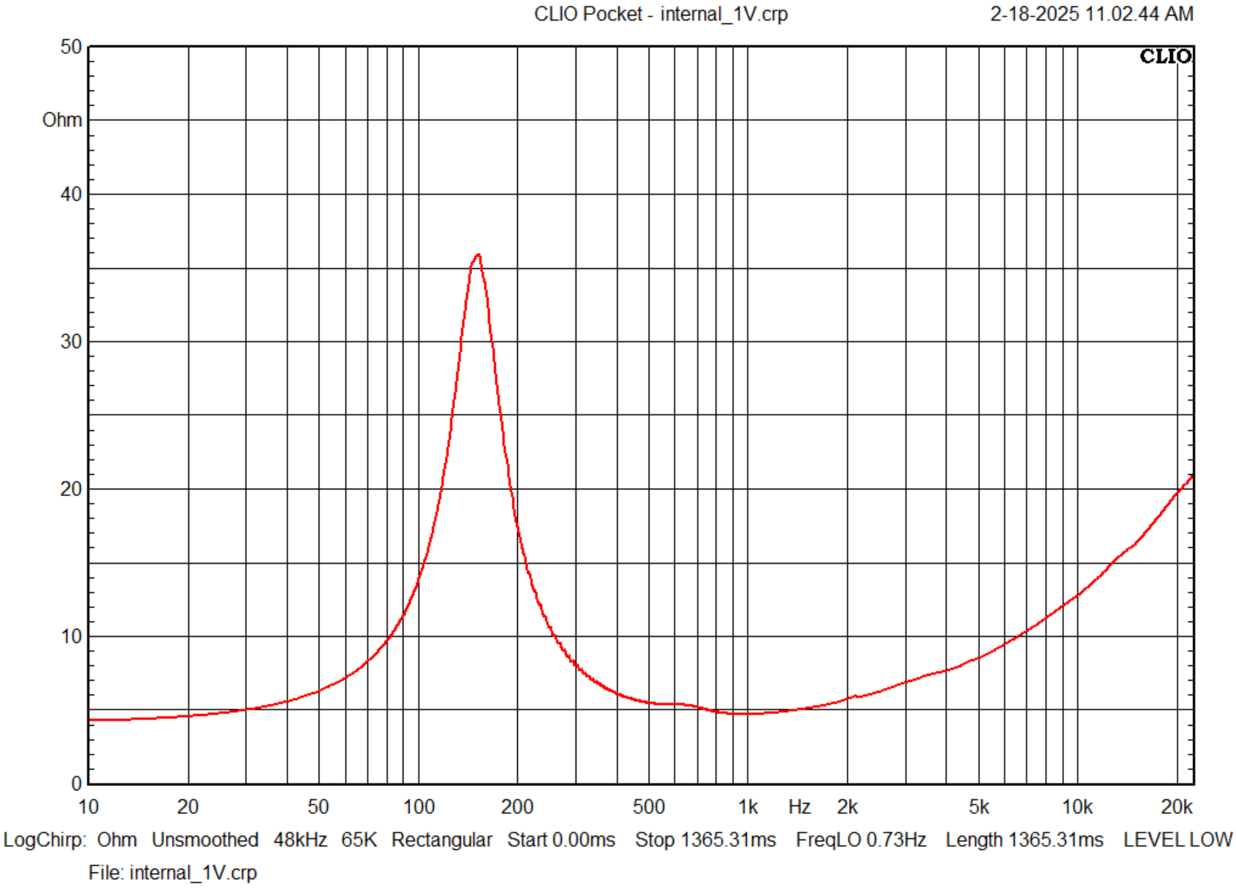



With this method the voltage generated by CLIO is known (as output level is calibrated), the output impedance $R_S$ is precisely known, as it is measured and stored in EEPROM during device production. Then, the current flowing in the loudspeaker is calculated by looping back the voltage at load to CLIO input using the loop button  in the software.




The whole process is automated in the software and leads to seamless operation, the software measures the voltage $V_X$ and automatically calculates the impedance of the connected loudspeaker.

Output level can be set according to the desired testing level. 1 V is a safe starting point. The impedance will appear as soon as the completion of the sweep sinusoidal stimulus.




However, this "internal" method has some limitations. The voltage output of the CLIO CP-01 box is limited to a maximum of 3.46 V, and the voltage at the loudspeaker terminals is lower and not constant as a function of frequency, as it is modulated by the loudspeaker’s own impedance. This occurs because the voltage is supplied through the CLIO CP-01 box's output impedance, which has a nominal value of 150 ohm. This measurement method, referred as “internal” in the CLIO software, is neither constant current nor constant voltage, but a combination of both.

While the "internal" technique is highly accurate and produces an impedance curve well-suited for calculating loudspeaker's Thiele-Small parameters, the user may prefer to test the loudspeaker with a higher voltage. This would better replicate real operating conditions, where a constant voltage drive might also be desired.

This is possible with CLIO Pocket using Math operations and combining LogChirp voltage and current measurements in a single impedance result.

We will need a few items to carry out this measurements, in particular a power amplifier to drive the loudspeaker under test is needed. We describe here the process step-by-step by showing two possible scenarios: using a shunt sensing resistor or a current probe.

The **amplifier** should be as linear as possible and **must be single ended**, i.e. one of its outputs should be referred to ground. **Amplifiers with bridged/floating outputs should be avoided** as this will create short circuits.

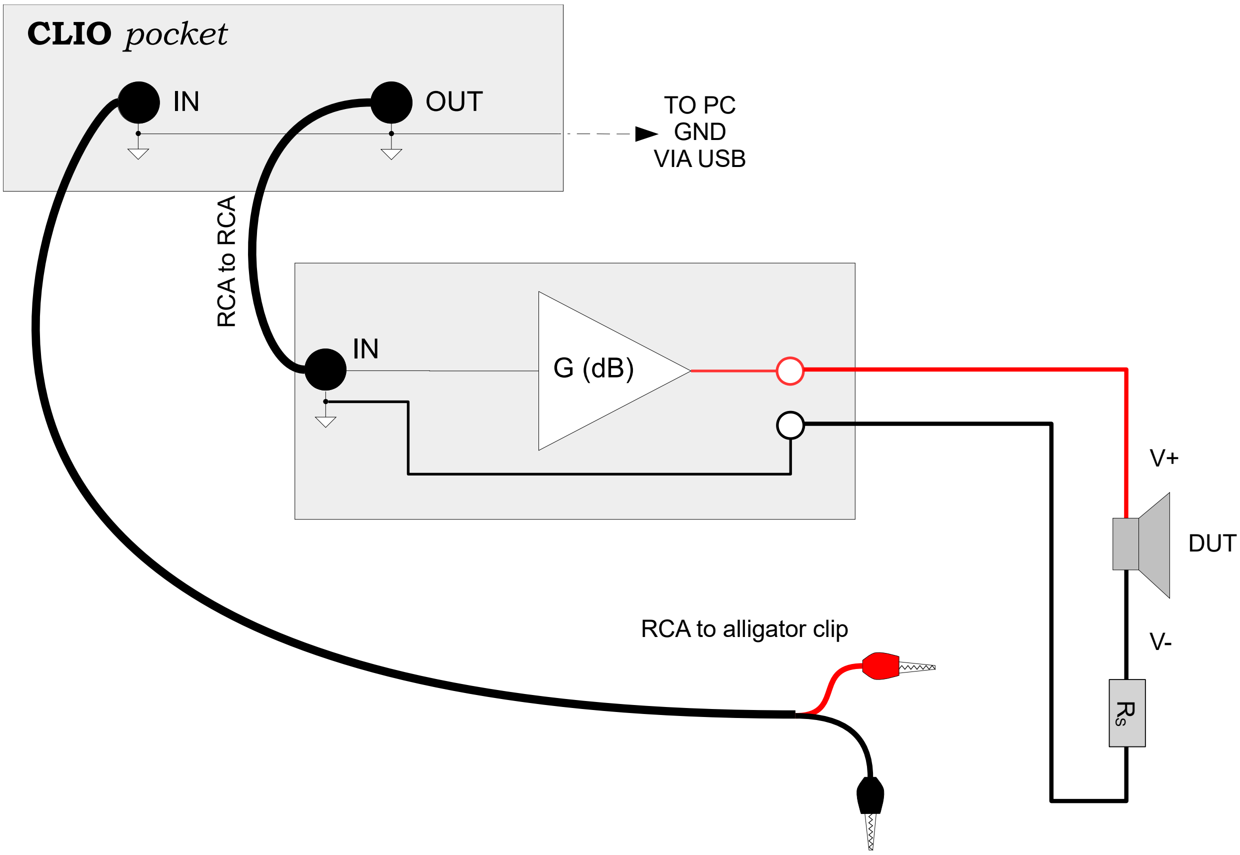
CLIO Pocket features a single-ended input and output, where the ground of the CP-01 box is sharing the same ground as the PC, connected via the USB port which provides both data and power to the box. The ground connection will be provided from CLIO Pocket output connection to the power amplifier input.

For the following measurements we will use the RCA to alligator clips cable provided with CLIO Pocket connected at CLIO input, always connecting the red clip only.

Please make sure that the amplifier you are using has a single-ended output referred to ground, also do not connect the black clip of the CLIO RCA to alligator clips cable, use exclusively the red clip.

# V/I METHOD USING AN EXTERNAL AMPLIFIER AND A SHUNT RESISTOR

In this first case we will need a power amplifier and a sensing resistor, plus some cables to arrange the connections.



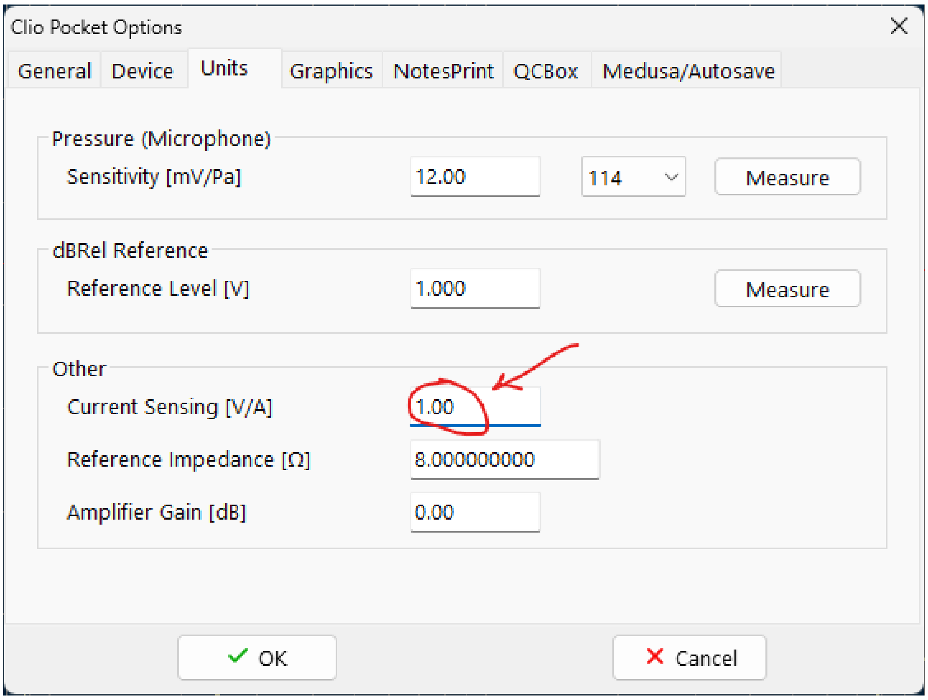

Let’s review the connections first: the CLIO output should be connected to the power amplifier input using the RCA CLIO output connector. Ground has to be provided to the power amplifier input using this connection, depending on the specific amplifier input connector a suitable adapter might need to be used.

The RCA to alligator clip cable should be connected to CLIO input ready to measure voltage at the loudspeaker terminals and over the sensing resistor.

The $R_S$ sensing resistor should be known with sufficient accuracy, as an uncertainty on the resistor value will be directly reflected on the uncertainty of the current reading. A simple trick is to use 10 resistors of same nominal value and tolerance in parallel as this would result in a resistor of 1/10 of the value but with better tolerance, since the deviation between devices in a batch is supposed to be random. The resistor value can also be measured using either an ohmmeter or a voltmeter with sufficient accuracy. The shunt resistor should have sufficient power handling. In this case, using a parallel configuration of 10 resistors is beneficial, as it distributes the current across 10 branches. We leave the math to the reader.

Let's assume here that the value of the shunt resistor is known, then the conversion factor should be set into the CLIO software.

Under Clio Pocket Options you should set the proper value for the Current Sensing, as in this case the sensing is provided by a resistor then the Current Sensing value in [V/A] is the same as the resistor value $R_S$ in ohm.



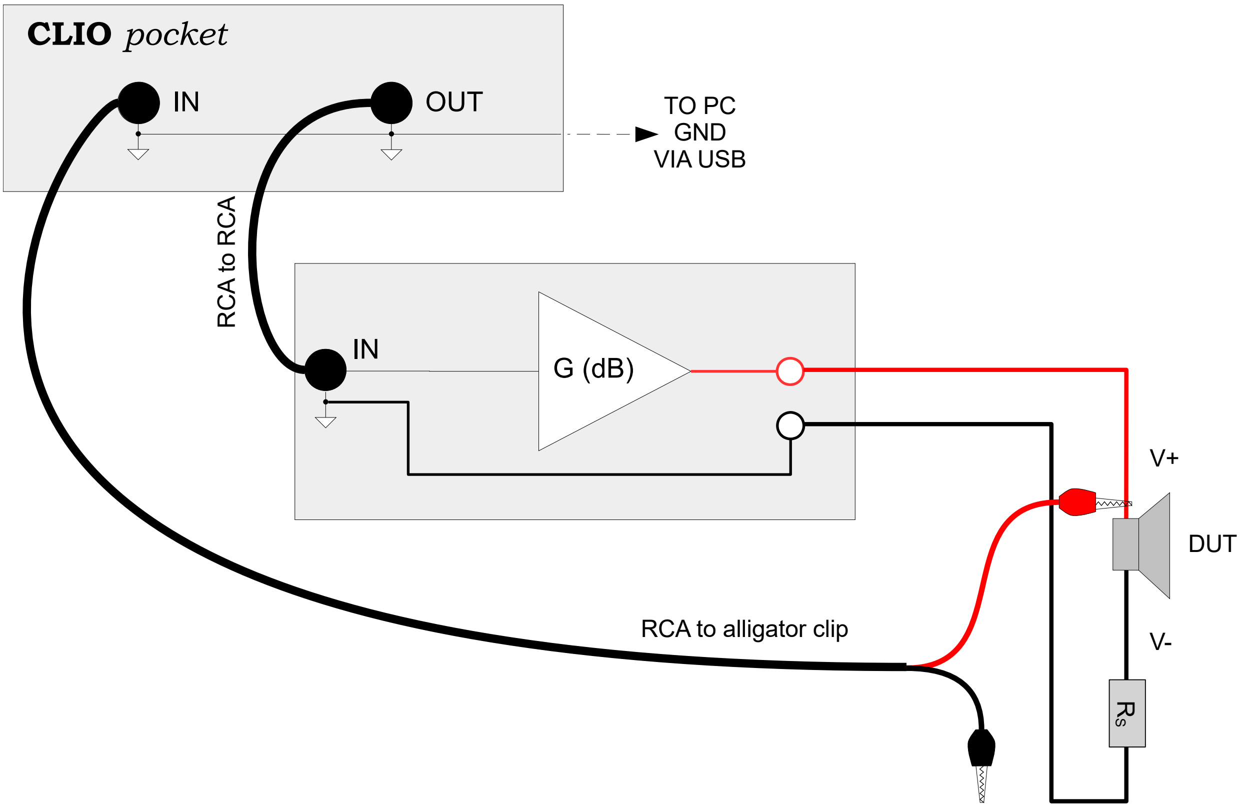

One's might ask which is the best $R_S$ value to use, a safe starting point for a loudspeaker is 1 ohm. For a more elaborate answer we invite you to read the AES paper "Loudspeaker Electrical Impedance Measurements Methods: A Brief Review" which is available from Audiomatica's web site. Spoiler, for maximum sensitivity the $R_S$ should be in the range of one tenth to ten times the tested loudspeaker impedance.

An high value of the shunt resistor raise the sensitivity of the current reading, which gives a better noise immunity. But, since the voltage at the loudspeaker terminal is modulated by the shunt resistor value, an high value results in a non constant voltage driving of the device under test, such in the case of the "internal" mode. A low value of the shunt resistor means lower sensitivity, which means that the current measurement will be more succeptible to noise, in particular around the resonance peak where the current is lower.

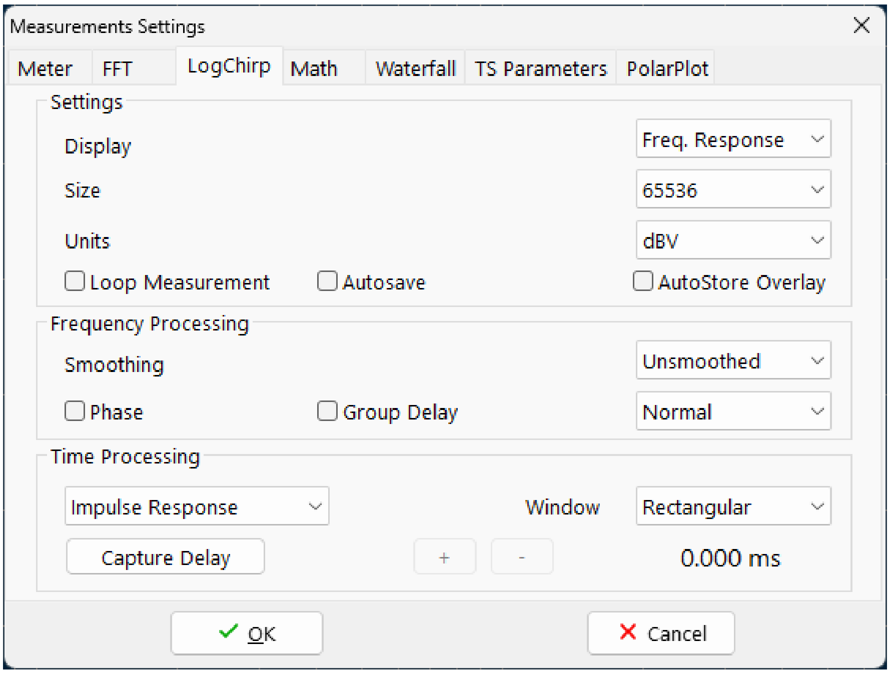
For our test we chose an 1 ohm resistor.

Three measurements should be carried out with LogChirp, first the voltage at loudspeaker V+ terminal, then the voltage at terminal V- and as a last the current over the sensing resistor.

Let's start with the V+ voltage measurement, following this connection scheme:




And with the following settings, notice the Size 65536 and the Units in dBV:

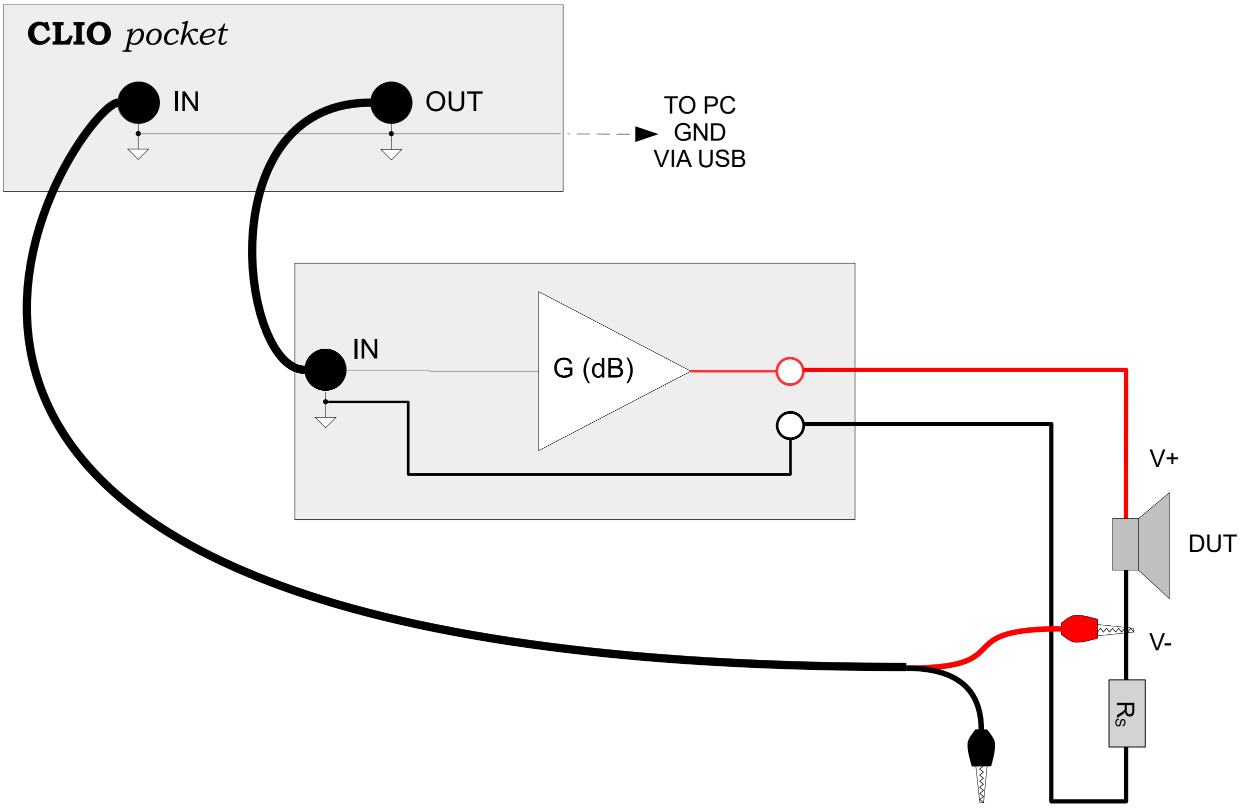



When executing the measurement please check that the input sensitivity is set to a proper value, if the sensitivity is too high the measurement is stopped and/or the OVERLOAD text is shown in the application status bar. If the sensitivity is too low, a message LEVEL LOW is shown. You can check the input level using the peak meter in the CLIO Pocket software graphical interface.

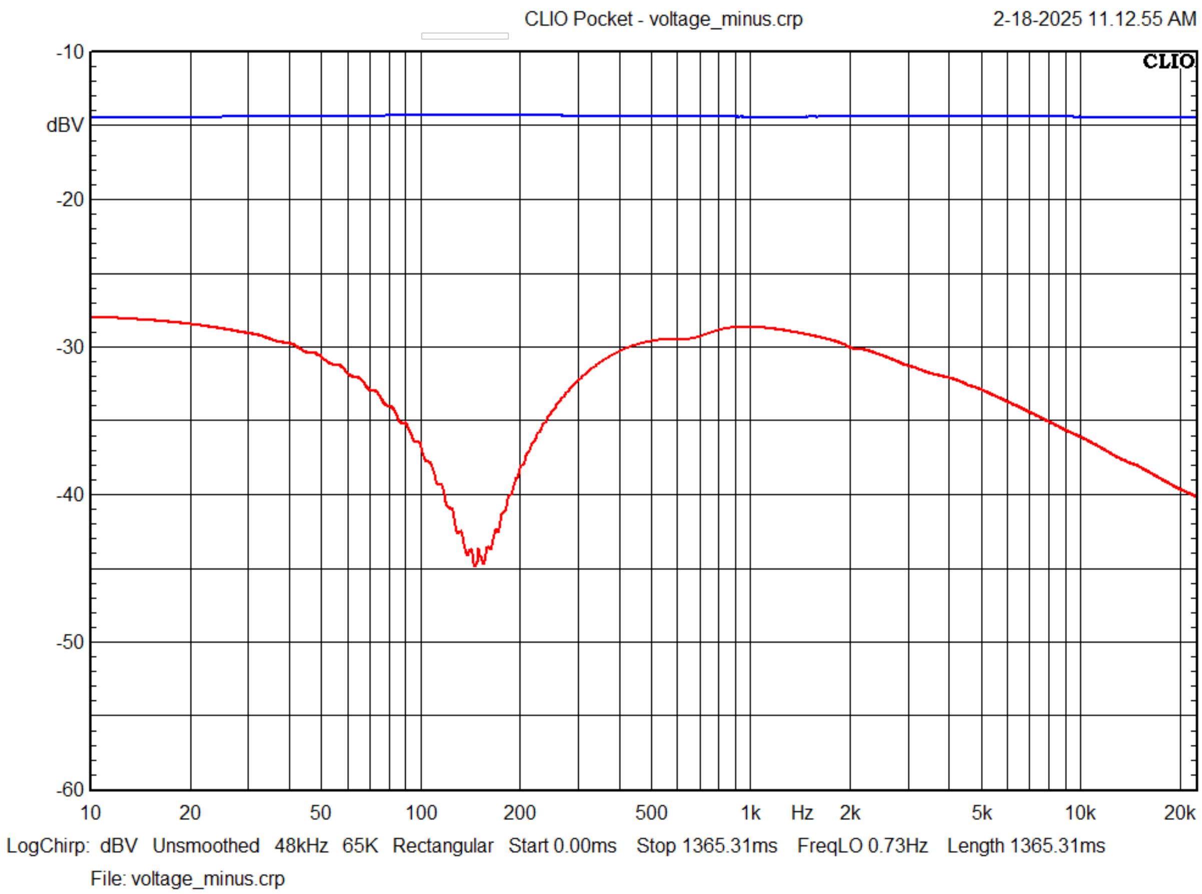
This measurement can be stored with a name which we can then remember like "voltage_plus.crp".

We now measure the voltage at the other loudspeaker terminal.

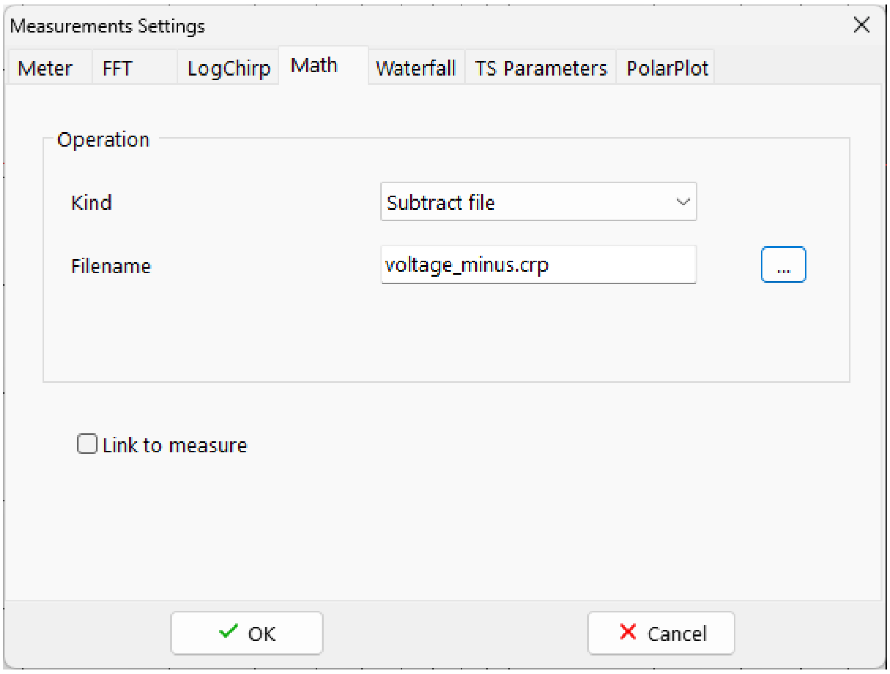
With the same measurement settings of the previous measurement, and the following connections:



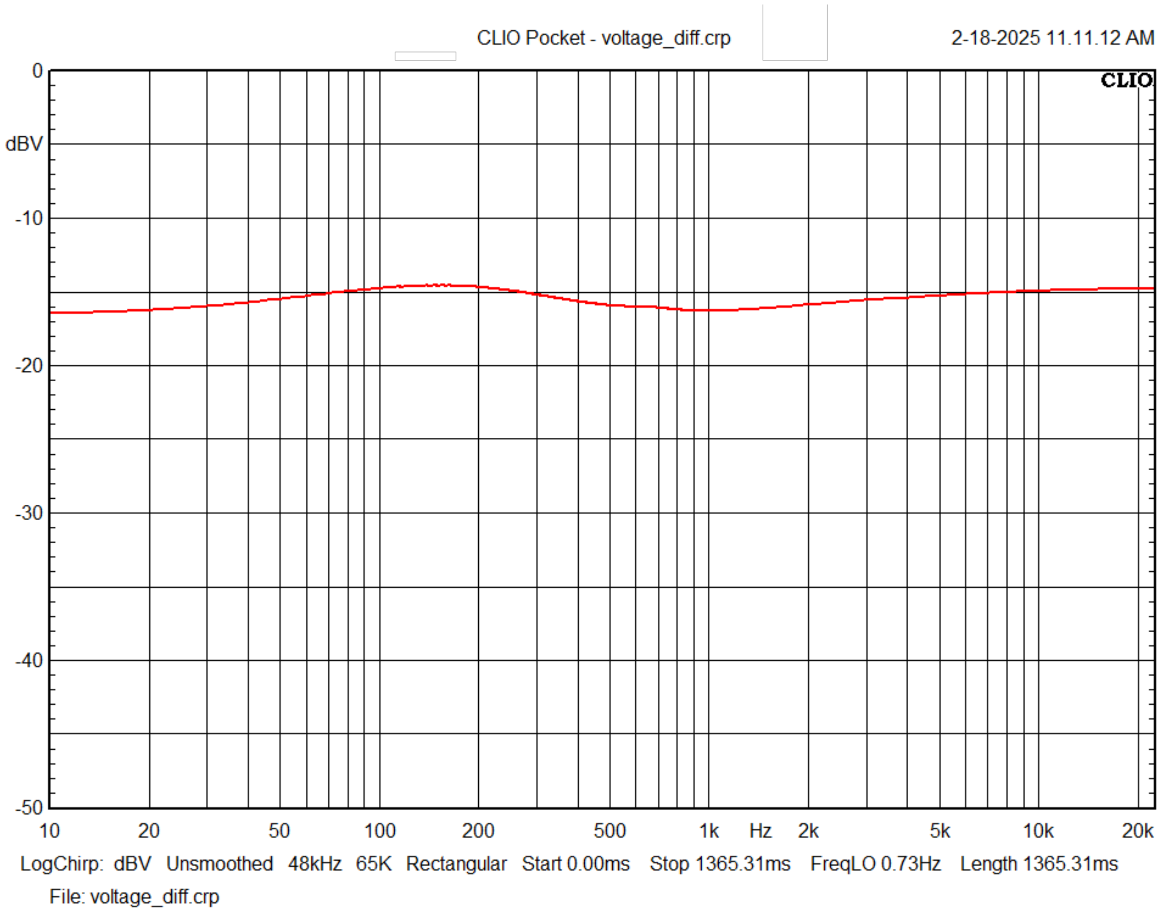

We can acquire a second voltage which we can save as ""voltage_minus.crp".



The differential voltage can be calculated using the subtract file Math operations. Open the "voltage_plus.crp", go to Math tools select "Subtract file" and choose the "voltage_minus.crp" file:

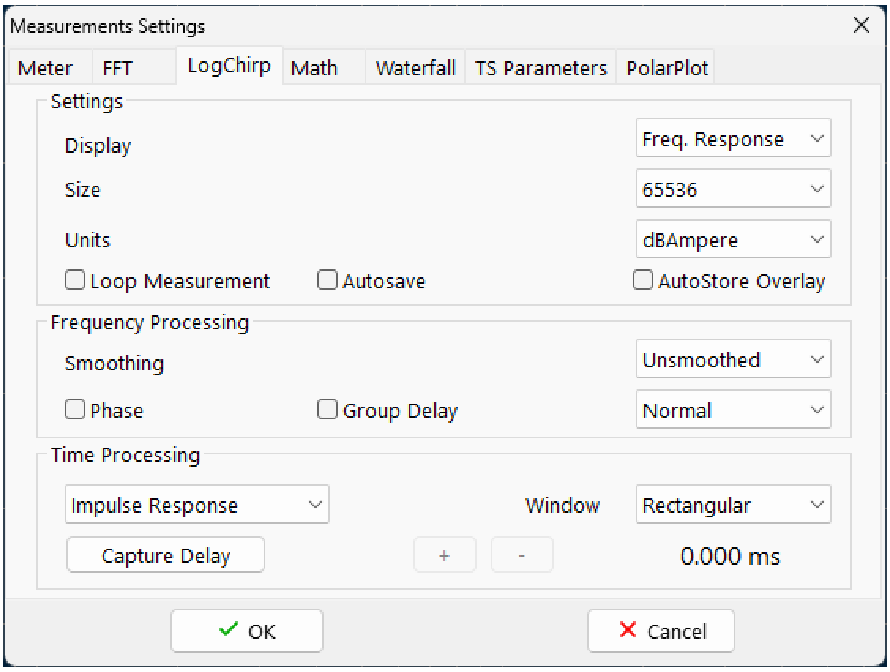


As a result we will get the differential voltage on the loudspeaker which we can save as "voltage_diff.crp":

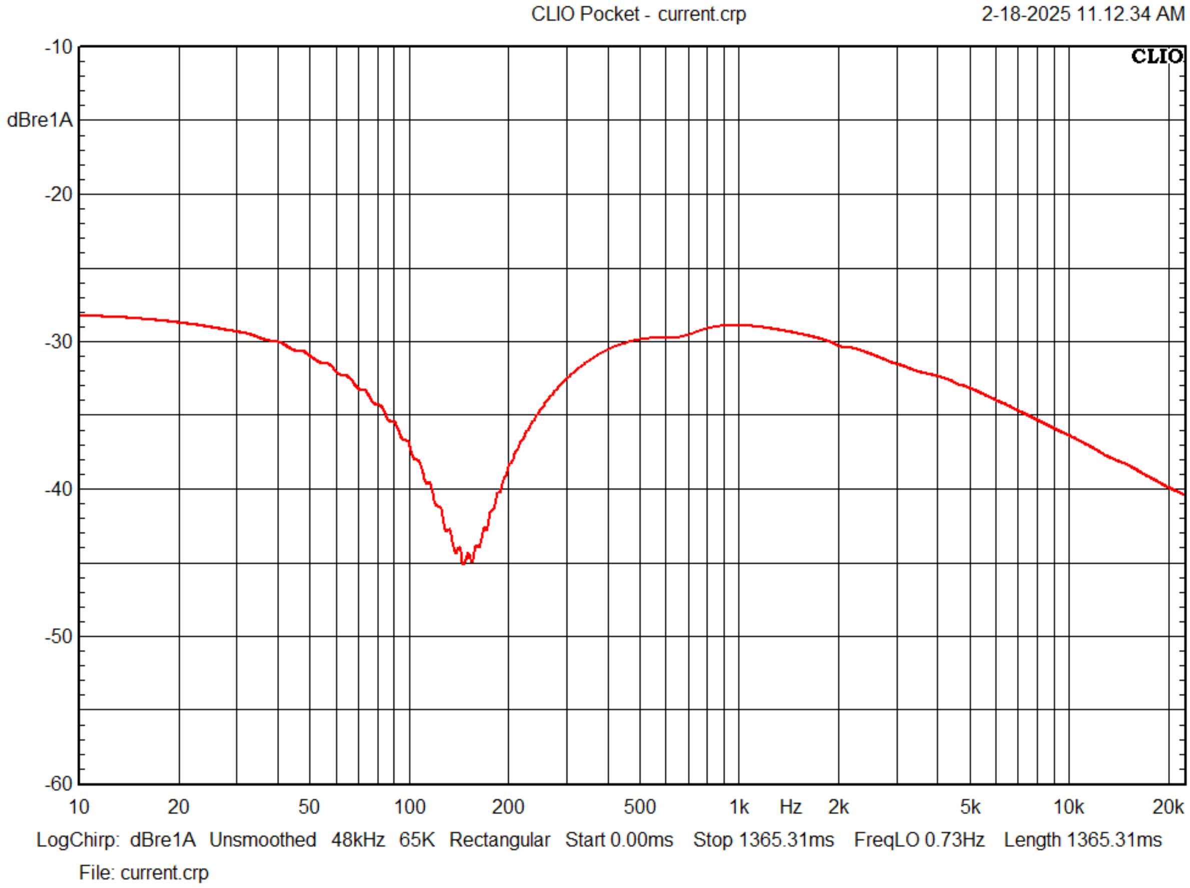



Without changing the connections, we can now measure the current flowing into the device under test, by measuring again at the same point over the shunt resistor.

Measurements settings should be modified in order to show the result as a current:

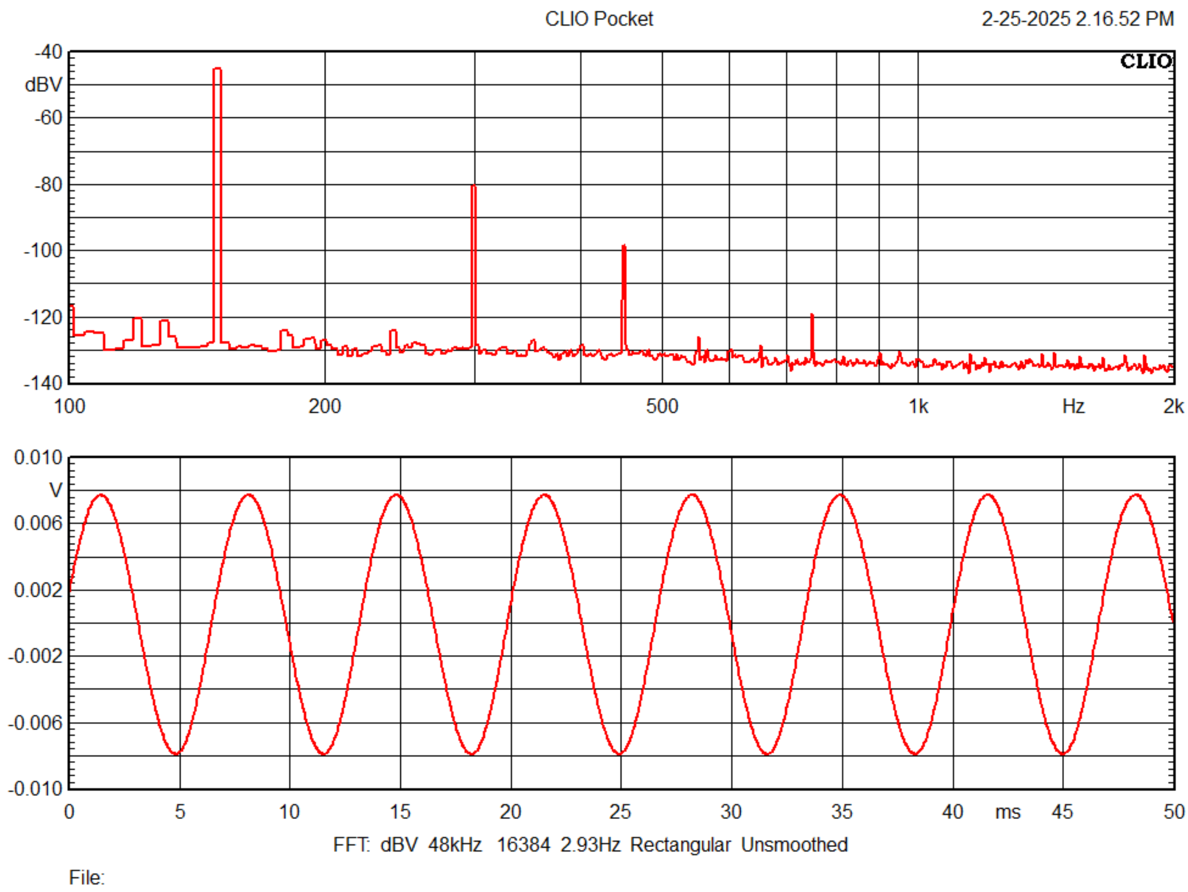


We run the LogChirp measurement again, notice that the units now are dBAmpere:



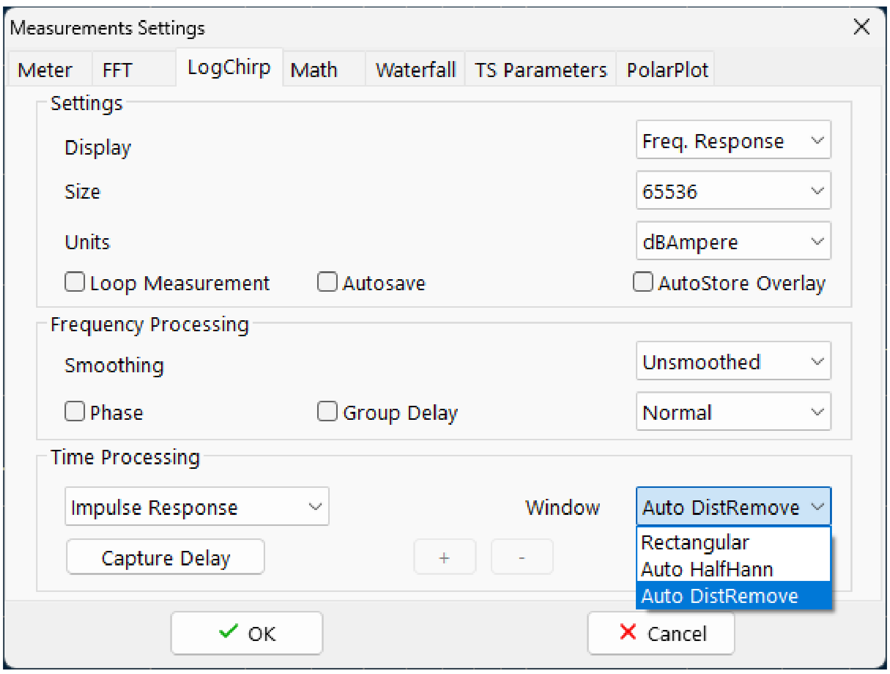

We note that there are some oscillations in the current measurement, in particular around the resonance peak of the loudspeaker. These were actually already present in the previous V- measurement, but were not visible in the differential voltage due to the difference in magnitude between V+ and V-.

The presence of non linearities in the current measurement is confirmed by running an FFT analysis of the current signal using a sinusoidal tone as a stimulus, where second and third order harmonic products are clearly visible. These are due to loudspeaker driver motor non-linearities, which are triggered by the actual displacement and current levels.

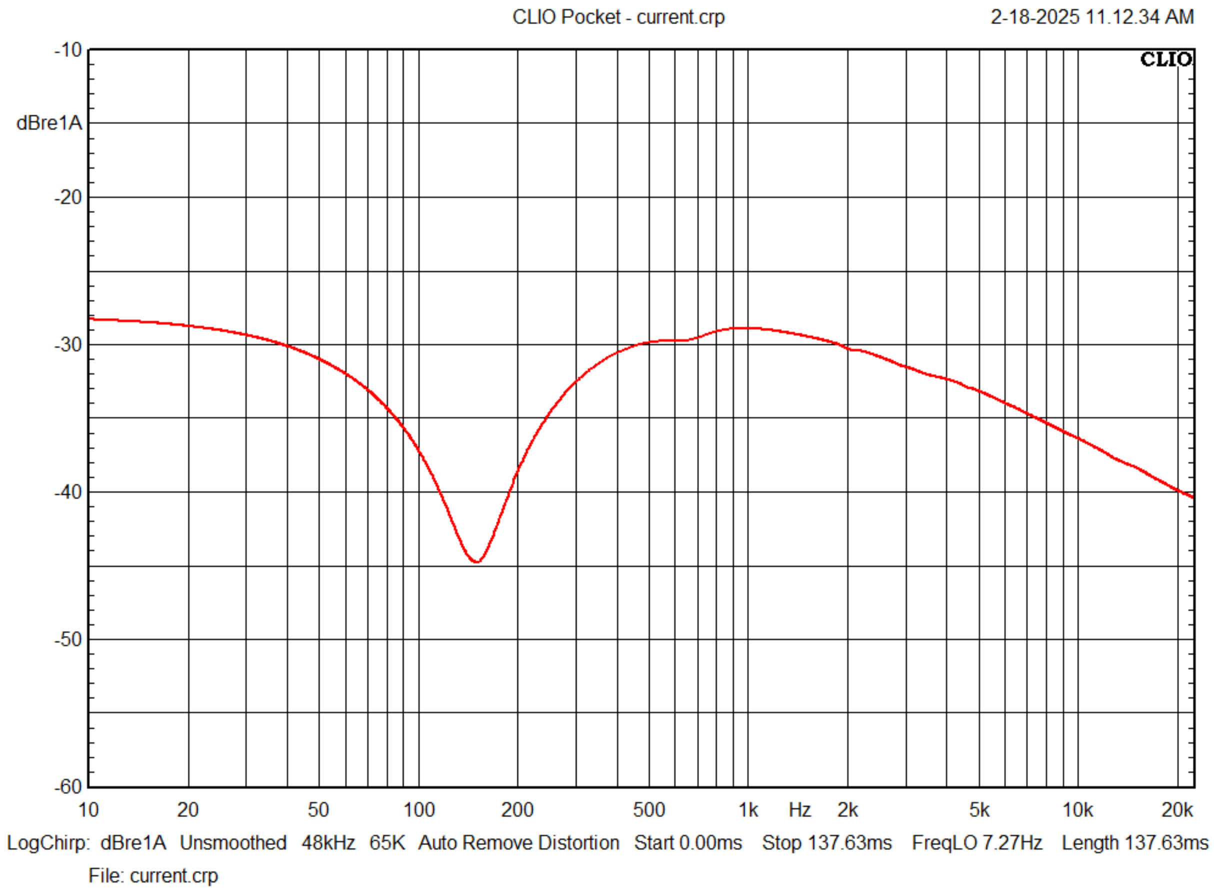



With CLIO Pocket release 3.10 we introduced a new time window option in LogChirp analysis called AutoDistRemove. This window is meant to be used to recover the linear response from the impulse response where distortions are not negligible. This process leverages the same tecnique used to calculate harmonic distortion orders from a LogChirp measurement.

To AutoDistRemove time window can be selected from the LogChirp tab of the Measurement Settings dialog:

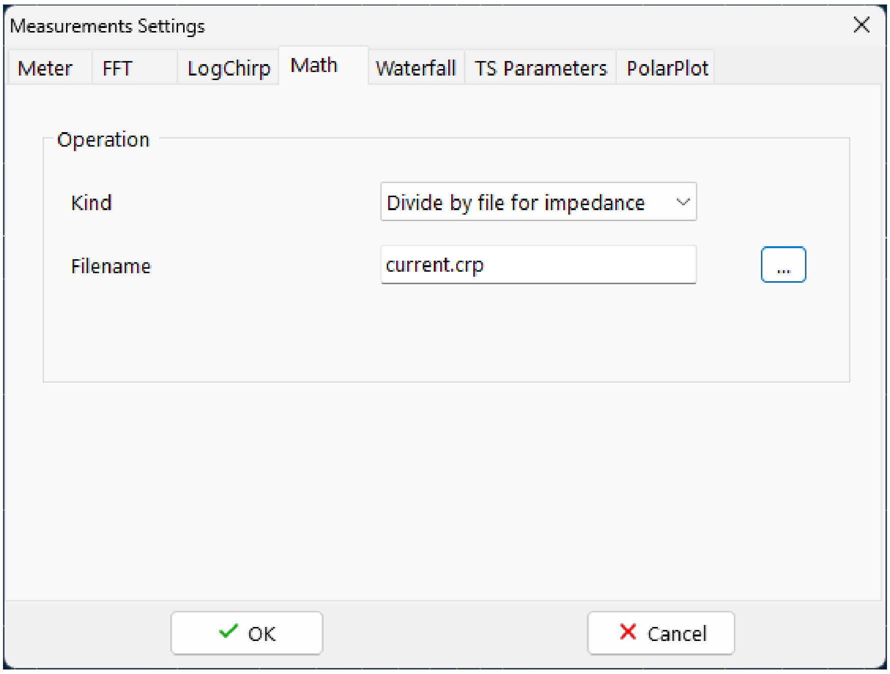


The current now does not show the ripples as before:

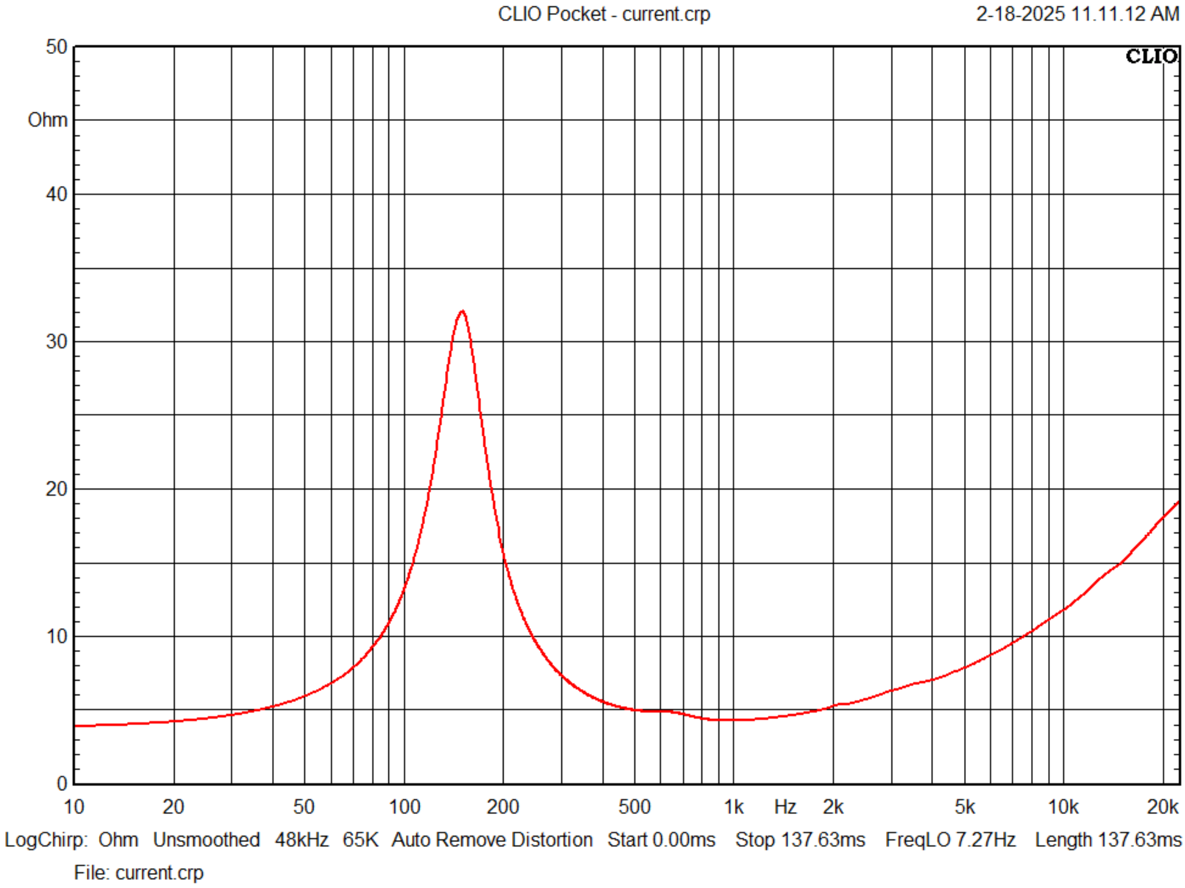



We can save the resulting file as "current.crp".

We can now reload the previous differential voltage measurement "voltage_diff.crp", and then enter into the Math tools tab from Measurements Settings again. Select Divide By File for Impedance and choose the current file "current.crp":



Pressing OK should result in the impedance:




This result can be saved in a new file, with the impedance as result of the voltage over current division.

If the value of the shunt resistor $R_S$ is very small compared to the DUT then we can avoid measuring the V- voltage, the error introduced by this omission is minimal.

# V/I METHOD USING AN EXTERNAL AMPLIFIER AND A CURRENT PROBE

An alternative and elegant solution to avoid the sensing resistor is the use of a current probe. Current probes with a pass band extending over the entire audio range are available but the cost of such devices can easily exceed the cost of CLIO Pocket resulting in a poor match. More affordable devices are also available, but users should consider the limited bandwidth. In our laboratory we tested an Hantek CC-65 current probe which has shown to be usable up to 10 kHz. We do not specifically endorse this device, we selected it because it was among the most affordable, had decent specifications, and was readily available at the time of writing.

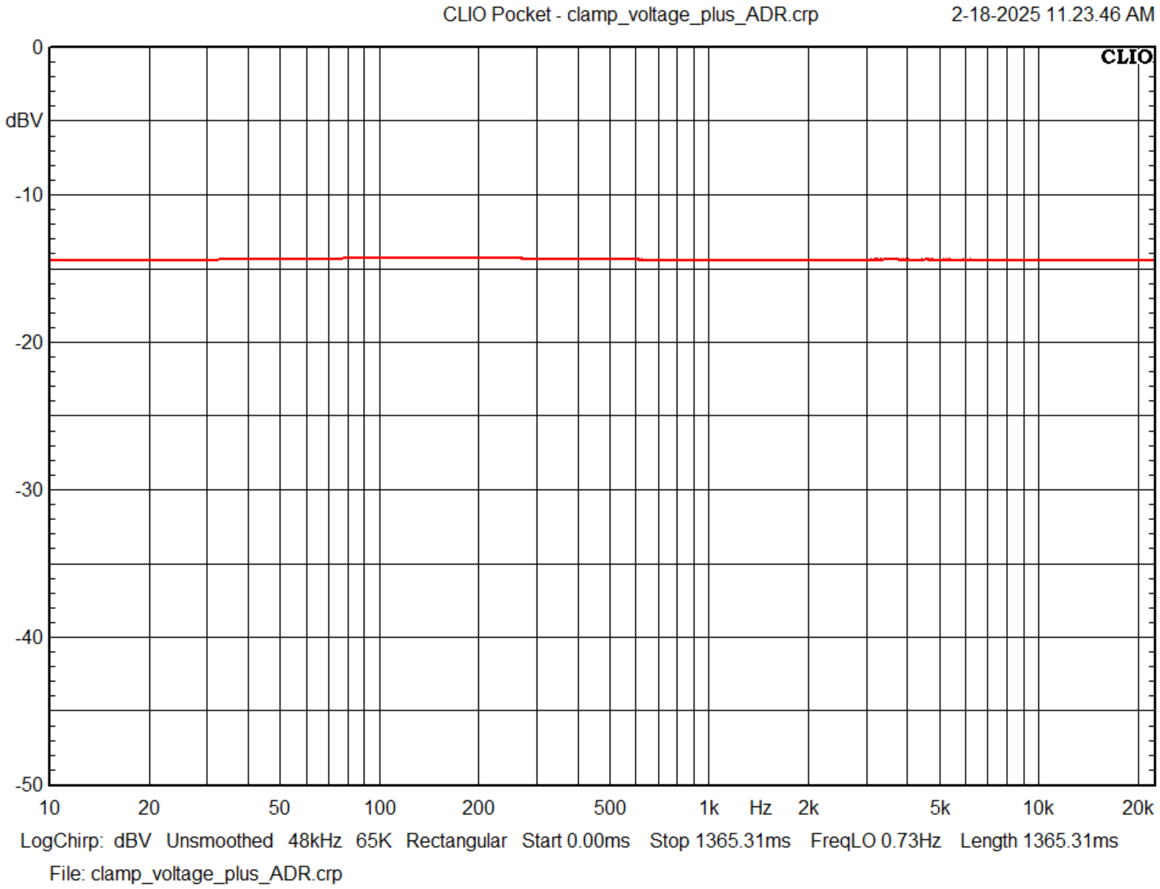
Moreover these inexpensive devices are quite noisy and affected by magnetic fields, which is unfortunate since we are dealing with loudspeakers possibly featuring massive magnets. A simple improvement to the performance of the current probe when measuring loudspeaker impedances is to multiply the sensitivity by looping the wire around the current clamp. In our tests we experimented that the inductance created by the wire loop is not affecting the impedance measurement, at least up to the 10 kHz usable frequency range of the probe.

In the case of our Hantek CC-65 current probe, set at its highest sensitivity 100 mV/A, and looping the cable 10 times, we get an equivalent sensitivity of 1 V/A.


This value should be entered into CLIO Pocket Options under the Current Sensing setting, as in this case the sensing is provided by the above current probe, then the Current Sensing value in [V/A] should be 1.

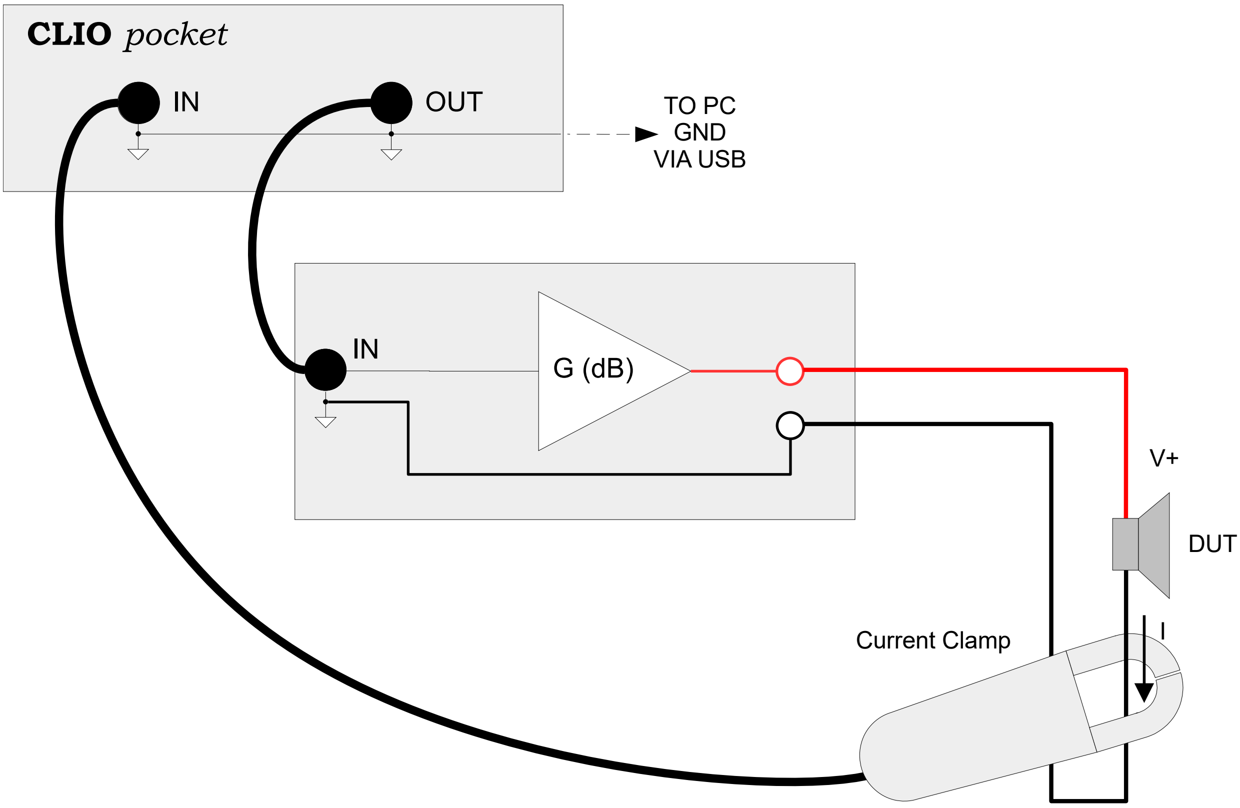
The V+ voltage should be measured using the same setup as before, while the current is directly measured using the current probe over one of the two cables connecting the DUT to the amplifier. Please refer to the markings on the current probe to get the correct polarity of the current sensing.

Let's start with the V+ voltage measurement, we use the same settings as in the previous case. Remember to connect the RCA to alligator clip cable to CLIO Pocket input, set the LogChirp measurement in dBV.

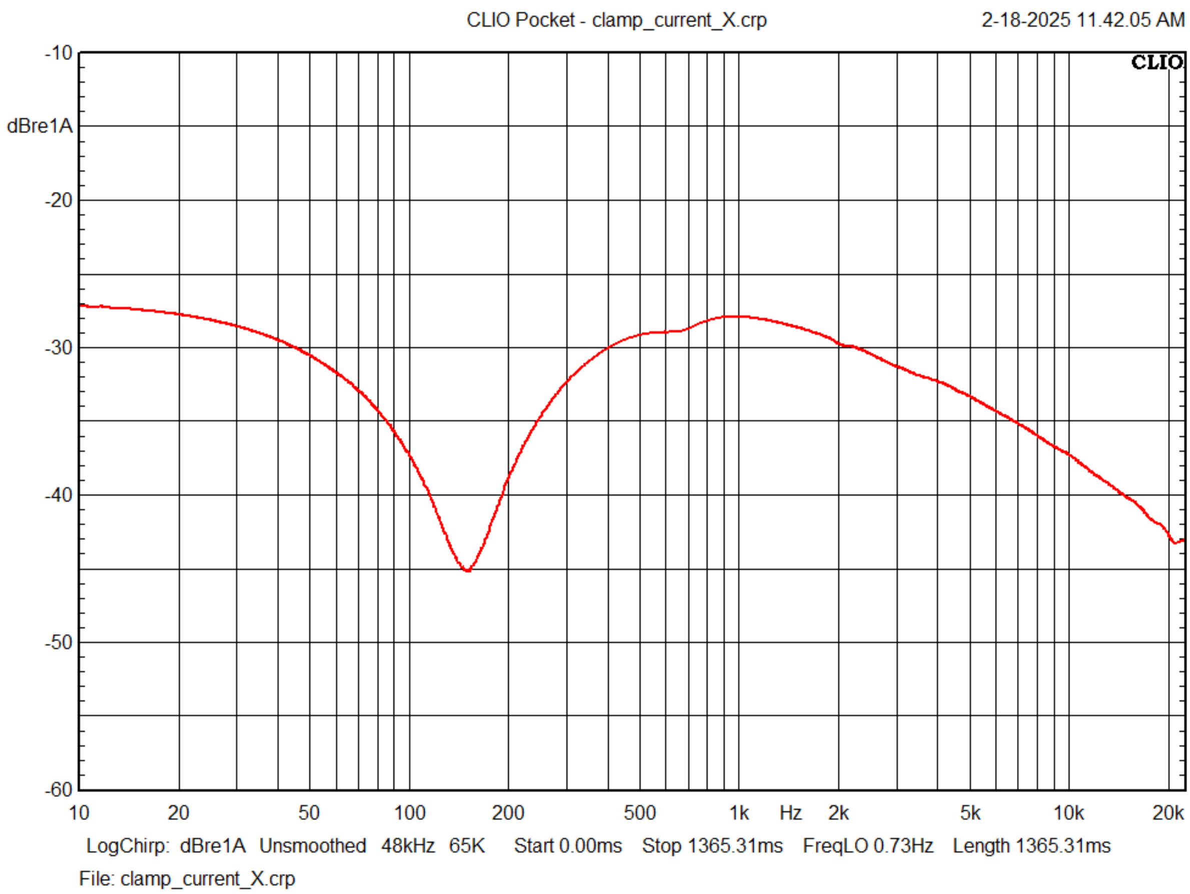



The current measurement has to be carried out in the same way as before, selecting dBAmpere as unit.

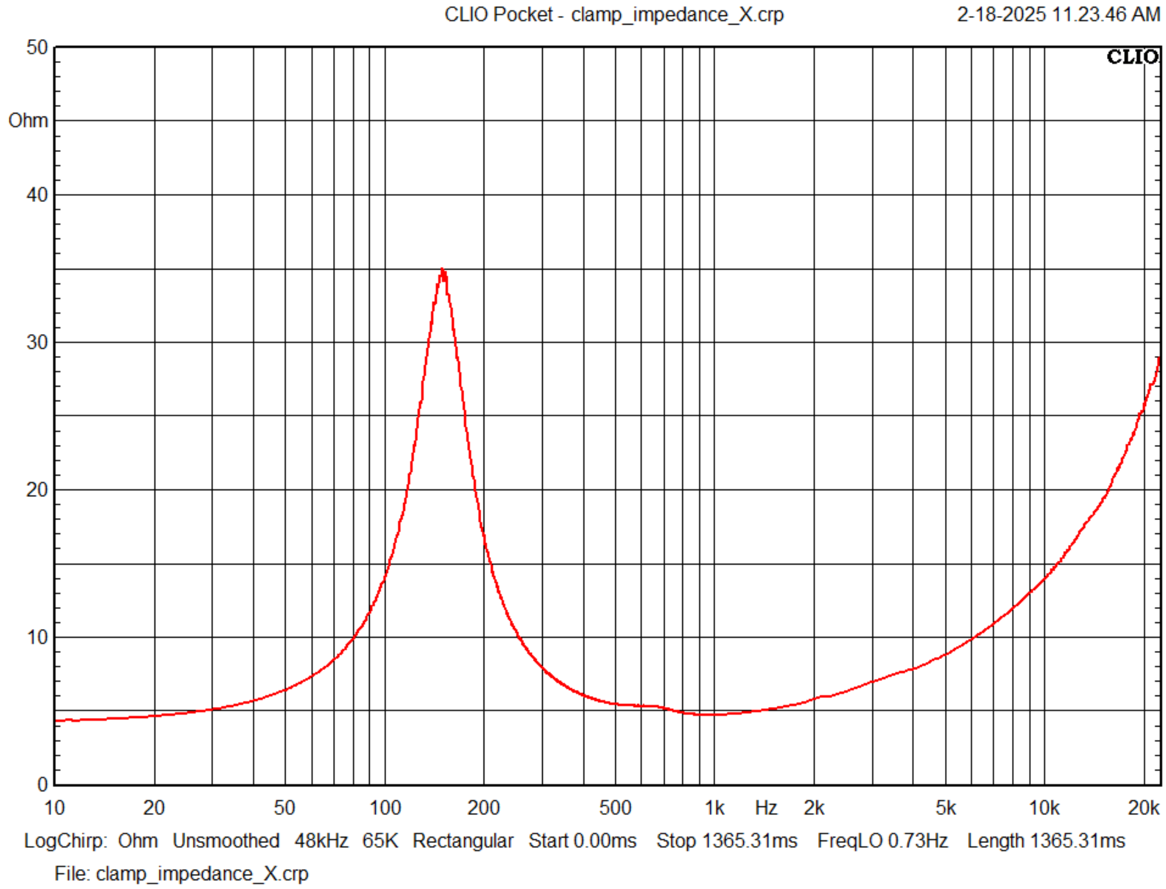
The current clamp output should be connected to the CLIO Pocket input:




We can run the measurement and get the current:



Once the voltage and current measurements are saved, we can reopen the voltage measurement and apply the "Divide by File for Impedance" processing selecting the latest current measurement.

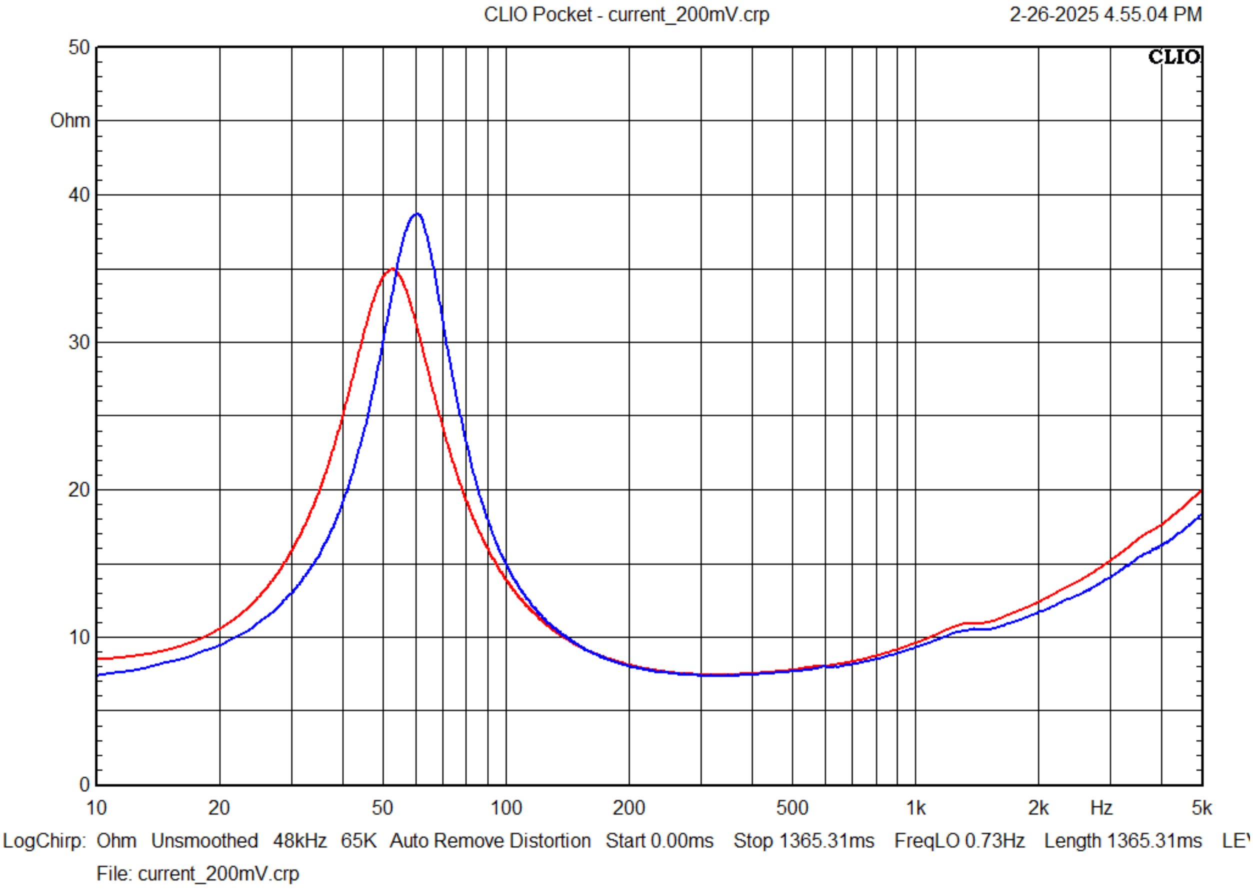


# EFFECTS OF THE DRIVING VOLTAGE ON IMPEDANCE CURVE

Measuring at different driving voltages affects the impedance curve due to changes of Parameters with level, especially Moving Mass $M_{MS}$ and Compliance $C_{MS}$, therefore $V_{AS}$. It is important to note that we are still in the linear behavior and this has nothing to do with dynamic parameters.

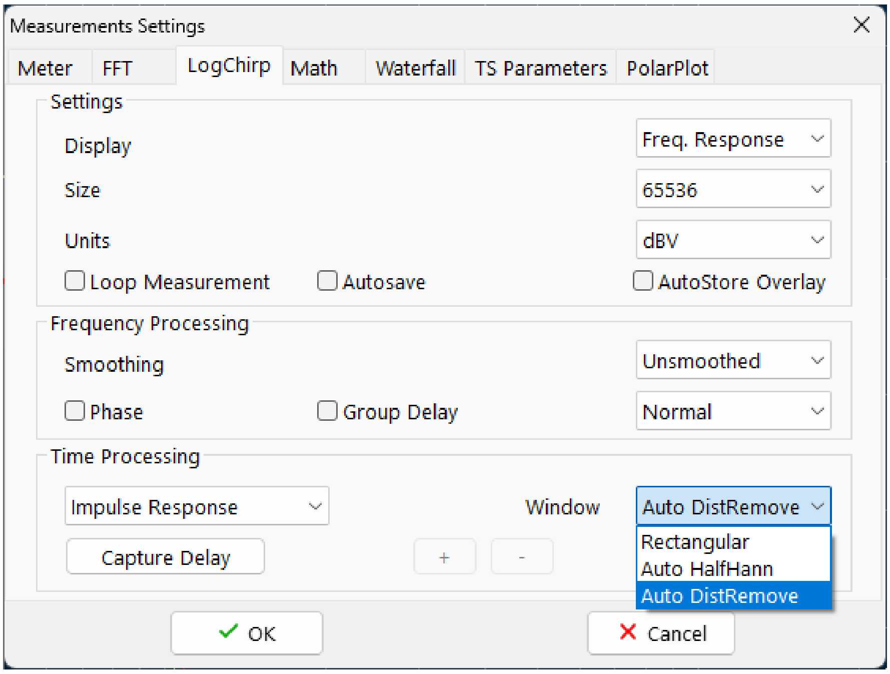
Also, should nothing change, the whole procedure described would be pointless.

This effect is clearly illustrated in the following graph, where a woofer loudspeaker driver was tested using the V/I technique described earlier, with voltages of 250 mV (blue curve) and 4 V (red curve). As shown, the resonance frequency decreases from 60 Hz to 52 Hz.

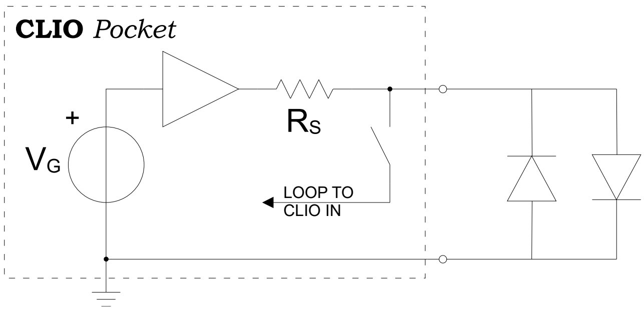


# REMOVING DISTORTIONS FROM LOGCHIRP RESPONSES

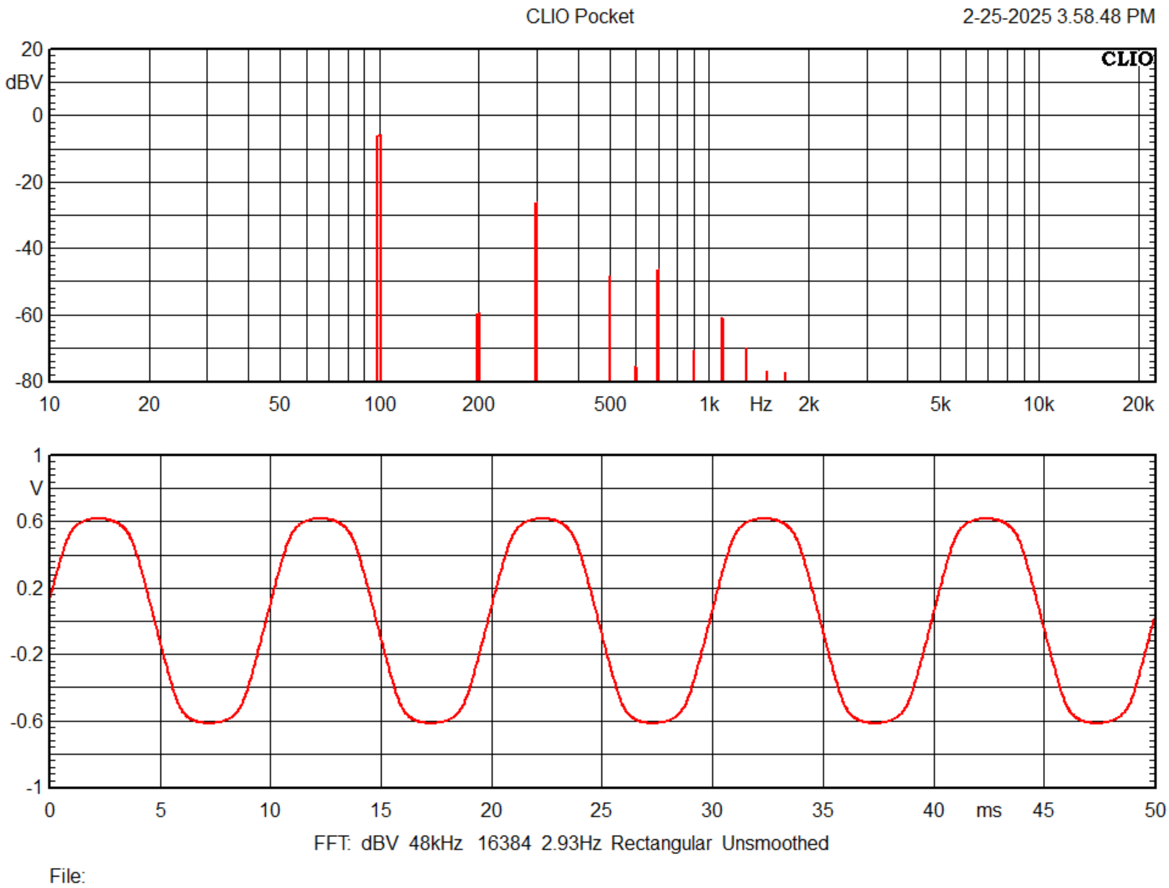
CLIO Pocket release 3.10 introduces a new time window option in LogChirp analysis called Auto DistRemove. This goes alongside the already available options: Rectangular and Auto HalfHann.




The LogChirp stimuli has the unique property to separate the harmonic distortion components as distinct impulses at the tail of the impulse response. Let's see a practical example, by connecting at the CLIO Pocket output two diodes:

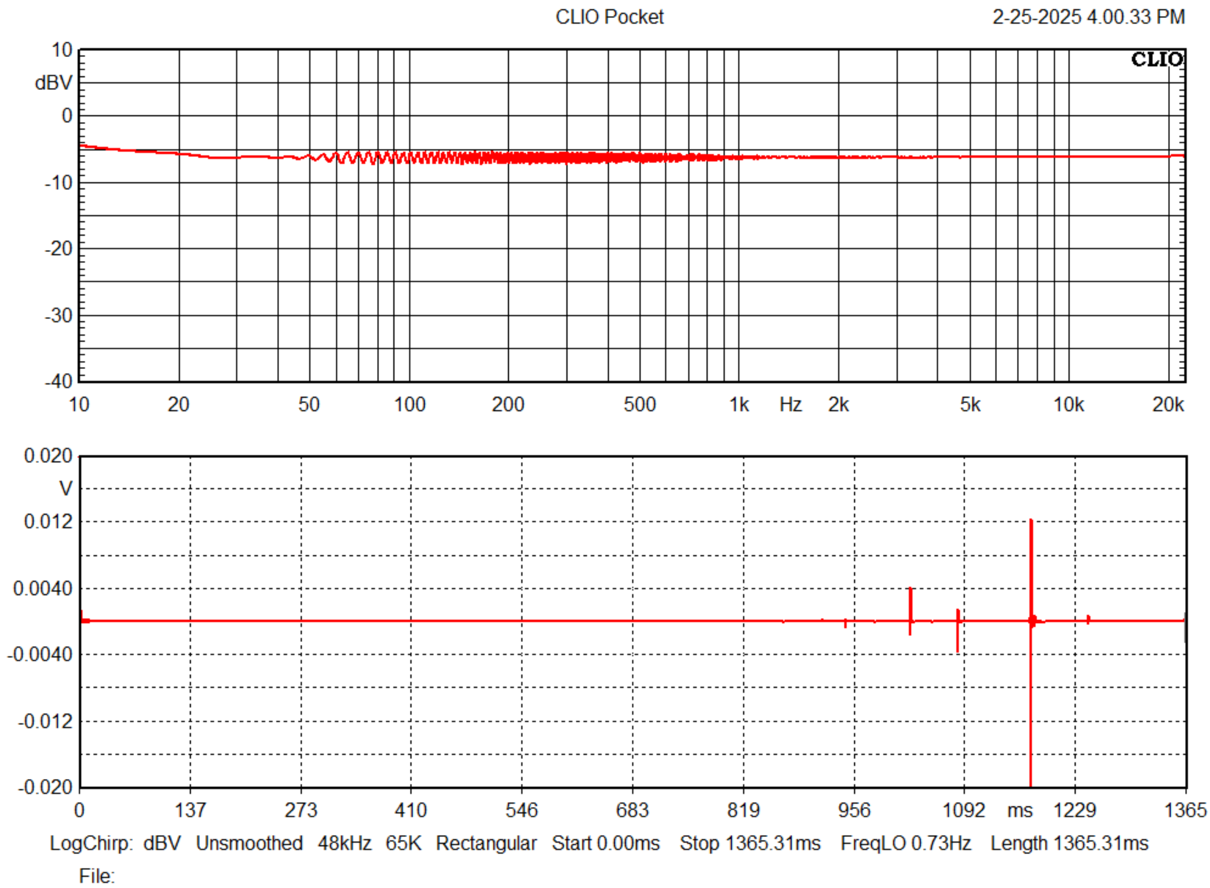


Activating the CLIO Pocket In-Out loop, we can read the voltage at the diodes. A noticeable odd-order distortion appears on the CLIO input as soon as the diodes begin to conduct. This can be easily seen using a 100 Hz sinusoidal tone and FFT analysis.




The multimeter reads 10% THD.

Using the same voltage output and setup we can run a LogChirp analysis:

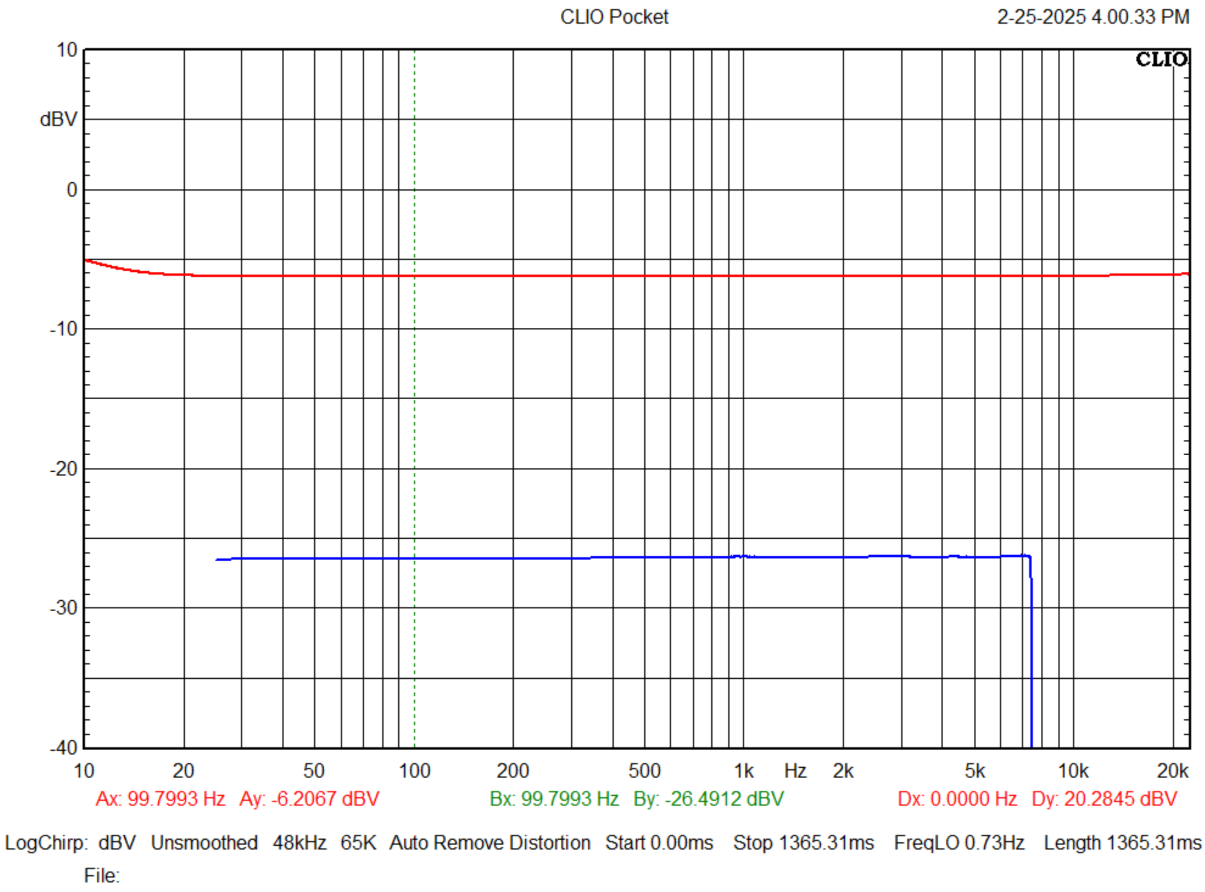



The LogChirp stimuli has the unique property to separate the harmonic distortion components as distinct impulses which shows up at the tail of the impulse response. These can be clearly seen in the above response.

When dealing with acoustical responses, which are usually featuring a time-of-flight delay, the usual Rectangular or AutoHalfHann windows are effectively windowing out the room reflections together with the distortion components. But in case of devices without delay, such as when measuring a voltage from the port of an electrical network, like a loudspeaker or a power amplifier, the Rectangular and Auto HalfHann time windows cannot be used because the very late part of the impulse response retain important data which cannot be discarded.

The Auto DistRemove time window should be used instead in all cases where the linear response of a device without delay has to be shown. The Auto DistRemove time window behaves similarly a Auto HalfHann but sets a stop time window to remove the distortion components while keeping the very last part of the Impulse Response.

Let's try to apply this window to the previous measurement.




The red curve is the linear part of the response calculated using the Auto DistRemove window, while the blue curve is the THD. It can be seen that the difference between the linear response and the THD is exactly 20 dB, i.e. 10% distortion.

The AutoDistRemove time window should be used instead the AutoHalfHann in all cases where the linear response of a device without delay has to be shown.