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StudentZone—ADALM2000 Activity: Measuring a Loudspeaker Impedance Profile

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Objective

The objective of this lab activity is to measure the impedance profile and the resonant frequency of a permanent magnet loudspeaker.

Background

The chief electrical characteristic of a dynamic loudspeaker is its electrical impedance as a function of frequency. It can be visualized by plotting it as a graph called the impedance curve.

The most common type of loudspeaker is an electromechanical transducer using a voice coil connected to a diaphragm or cone. The voice coil in moving coil loudspeakers is suspended in a magnetic field provided by a permanent magnet. As electric current flows through the voice coil, from an audio amplifier, the electromagnetic field created by the current in the coil reacts against the permanent magnet's fixed field and moves the voice coil (also the cone). An alternating current will move the cone back and forth. The movement of the cone vibrates the air, producing the sound.

The moving system of the loudspeaker, including the cone, cone suspension, spider, and voice coil, has a certain mass and compliance. This is most commonly modeled as a simple mass suspended by a spring that has a certain resonant frequency at which the system will vibrate most freely.

This frequency is known as the free-space resonance of the speaker and is designated by F_S. At this frequency, since the voice coil is vibrating with the maximum peak-to-peak amplitude and velocity, the back EMF generated by coil motion in a magnetic field is also at its maximum. This causes the effective electrical impedance of the speaker to be at its maximum at F_S, known as Z_{MAX}. For frequencies just below resonance, the impedance rises rapidly as the frequency approaches F_S and is inductive in nature. At resonance, the impedance is purely resistive and beyond it, as the impedance drops, it looks capacitive. The impedance reaches a minimum value, Z_{MIN}, at some frequency where the behavior is mostly (but not perfectly) resistive over some range of frequencies. A speaker's rated or nominal impedance, Z_{NOM}, is derived from this Z_{MIN} value.

Knowing the resonant frequency and the minimum and maximum impedances is important when designing crossover filter networks for multiple driver speakers and the physical enclosure the speakers are mounted in.

Loudspeaker Impedance Model

To help understand the measurements we are about to make, a simplified electrical model of a loudspeaker is shown in Figure 1.

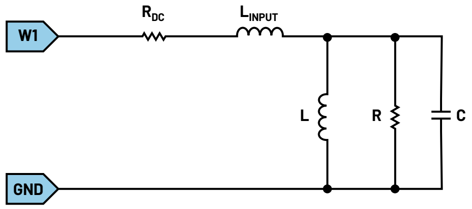


Figure 1. A loudspeaker impedance model.

The circuit in Figure 1 has a DC resistance placed in series with a lossy parallel resonant circuit made up of L, R, and C, which models the dynamic impedance of the speaker over the frequency range of interest.

- R_{DC} is the DC resistance of the loudspeaker as measured with a DC ohm meter. The DC resistance is often referred to as the DCR in a speaker/subwoofer data sheet. The DC resistance measurement is usually less than the driver's nominal impedance Z_{NOM}. R_{DC} is typically less than the specified loudspeaker impedance and the novice loudspeaker enthusiast may be fearful that the driver amplifier will be overloaded. However, because the inductance (L) of a speaker increases with an increase in frequency, it is unlikely that the driver amplifier sees the DC resistance as its load.
- L is the voice coil inductance usually measured in millihenries (mH). Typically, the industry standard is to measure the voice coil inductance at 1000 Hz. As frequencies increase above 0 Hz, there is a rise in impedance above the R_{DC} value. This is because the voice coil acts as an inductor. Consequently, the overall impedance of a loudspeaker is not constant but can be represented

as a dynamic profile that changes with input frequency as we will see when we make measurements. The maximum impedance, Z_{MAX}, of the loudspeaker occurs at the resonant frequency, F_S.

- F_S is the resonant frequency of a loudspeaker. The impedance of a loudspeaker reaches its maximum at F_S. The resonant frequency is the point at which the total mass of the moving parts of the loudspeaker becomes balanced with the force of the speaker suspension when in motion. The resonant frequency information is important to prevent an enclosure from ringing. In general, the mass of the moving parts and the stiffness of the speaker suspension are the key elements that affect the resonant frequency. A vented enclosure (bass reflex) is tuned to F_S so that the two work in unison. As a rule, a speaker with a lower F_S is better for low frequency reproduction than a speaker with a higher F_S.
- R represents the mechanical resistance of a driver's suspension losses.

Materials:

- ADALM2000 Active Learning Module
- Solderless breadboard
- One 100 Ω resistor (or any similar value)
- One loudspeaker, it is best if the speaker is one with a cone diameter larger than 4" such that it has a relatively low resonant frequency.

RMS Voltage Measurement

Hardware Setup

Build the circuit shown in Figure 2, preferably using your solderless breadboard. The loudspeaker can be in an enclosure or not.

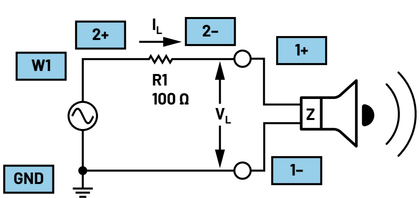


Figure 2. A speaker measurement setup.

Procedure

In Scopy, start the signal generator and generate a sine waveform with 8 V peak-to-peak amplitude and 100 Hz frequency.

Start the voltmeter and set both channels to AC (20 Hz to 800 Hz). Using the voltmeter tool, we can calculate the speaker impedance Z at a single frequency by dividing the rms voltage across the speaker (Channel 1 rms voltage) by the rms current through the speaker (Channel 2 rms current). The rms current can be computed as the rms voltage on Channel 2 divided by the resistance of R1 or 100 Ω. Try setting the signal generator to a few different frequencies and see how the voltage across the speaker and the calculated Z changes.

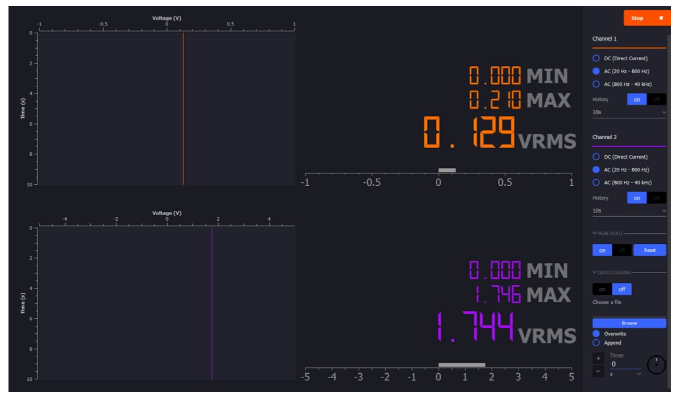


Figure 4. rms voltage across the loudspeaker.

You can plot the calculated impedance Z vs. frequency. The frequency of the signal generator is set in steps of 100 Hz and for each frequency you compute Z. The speaker impedance is small, approximately equal to the DC resistance in the linear region but is much higher at the resonance frequency F_S. An example plot is shown in Figure 5. Your speaker will probably look different than this.

Frequency Response

Hardware Setup

To plot the frequency response, make the connections as shown in Figure 5.

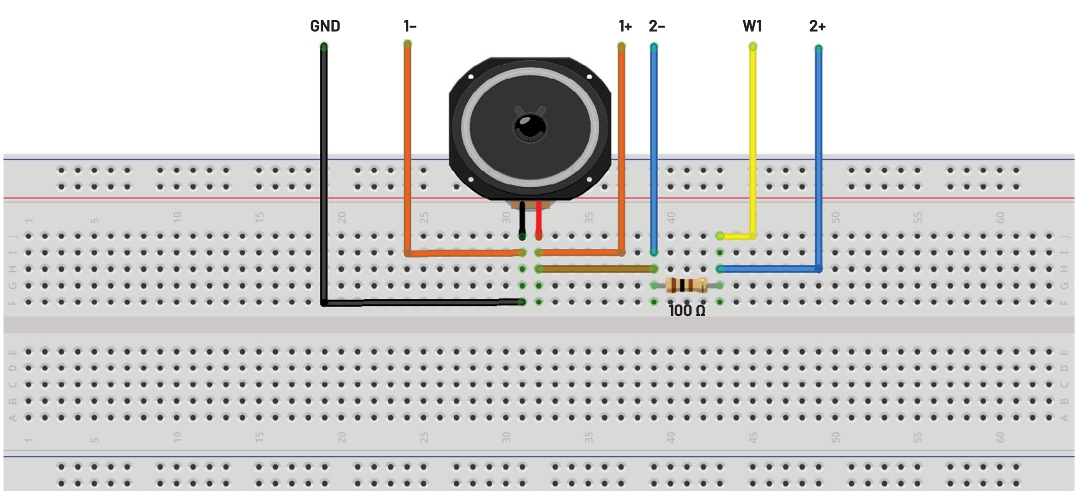


Figure 3. A speaker measurement setup for VL and IL.

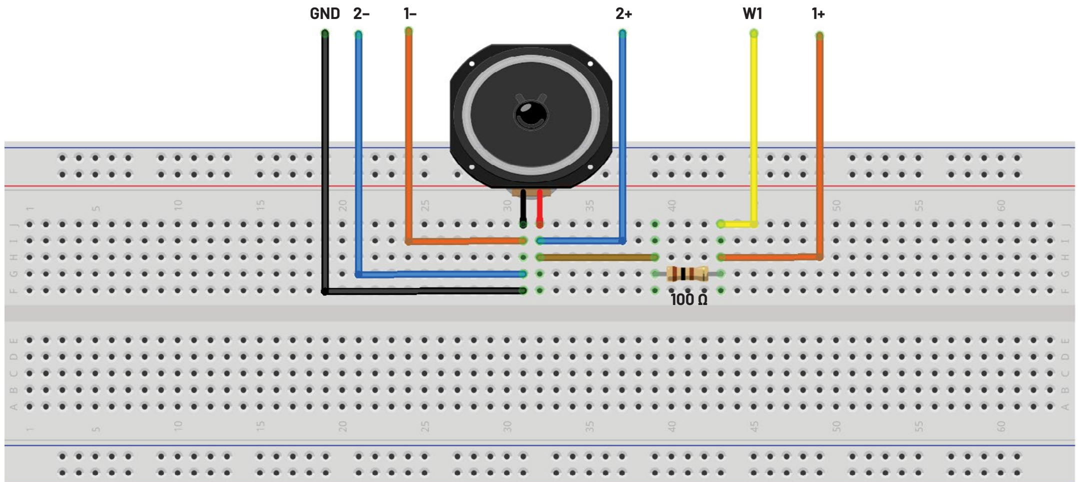


Figure 5. Breadboard connections for plotting the frequency response.

Procedure

In the network analyzer tool, you will do a logarithmic sweep. Set the start frequency to 100 Hz and the stop frequency to 1 kHz. Set the phase to vary from –30° to +30° and the magnitude from 0 dB to 10 dB.

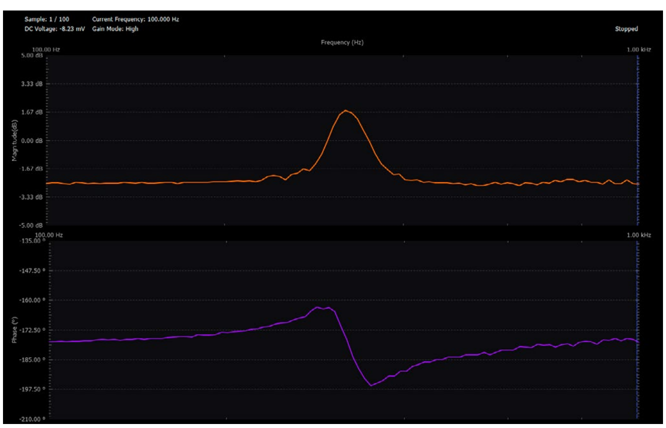


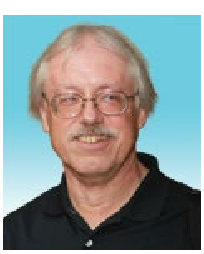
Figure 6. Frequency sweep of the loudspeaker circuit.

Questions:

1. Enumerate the main elements that are found in the loudspeaker impedance model.

2. For the frequency sweep of the loudspeaker circuit in Figure 6, determine the F_S and BW values.

You can find the answer at the StudentZone blog.



About the Author

Doug Mercer received his B.S.E.E. degree from Rensselaer Polytechnic Institute (RPI) in 1977. Since joining Analog Devices in 1977, he has contributed directly or indirectly to more than 30 data converter products and holds 13 patents. He was appointed to the position of ADI Fellow in 1995. In 2009, he transitioned from full-time work and has continued consulting at ADI as a fellow emeritus contributing to the Active Learning Program. In 2016, he was named engineer in residence within the ECSE department at RPI.

About the Author

Antoniu Miclaus is a system applications engineer at Analog Devices, where he works on ADI academic programs, as well as embedded software for Circuits from the Lab®, QA automation, and process management. He started working at ADI in February 2017 in Cluj-Napoca, Romania. He is currently an M.Sc. student in the software engineering master's program at Babes-Bolyai University and he has a B.Eng. in electronics and telecommunications from Technical University of Cluj-Napoca.