

Audio Characterization Primer

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Home Audio Amplifiers

ABSTRACT

Performing frequency response characterization on a speaker system requires minimizing nonlinearities of measurement technique for accurate measurements. This paper discusses methods that minimize measurement error to capture an accurate representation of a system's performance. With an accurate measurement, equalization filters could be applied to the system in order to achieve a desired response.

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1 Introduction

Performing frequency response characterization on a speaker system requires minimizing nonlinearities of measurement technique for accurate measurements. This paper discusses an introduction to the types of errors introduced in audio measurements, methods used to minimize measurement error, tools needed to set up a measurement system, and a walk through of a sample measurement for a given system.

2 Ideal Audio Measurement Environment

A test setup capturing a system's frequency response will return the real performance of the system under test, free of controllable nonlinearities introduced by measurement technique and environment. In practice there is no perfectly linear measurement environment, however, there are methods (with varying degrees of difficulty and investment of resources) that can mitigate a high percentage of measurement error. An ideal frequency response is measured in an anechoic chamber which removes reflections of both low and high frequencies. The reference microphone is calibrated over the audio range for response nonlinearity and a microphone-specific calibration file is used with measurement software to mitigate microphone error. The measurement software calibrates out error introduced by the audio interface (pre-amp and A/D nonlinearities). The microphone placement is setup on the same plane as the tweeter to avoid high-frequency directionality effects, and the microphone is situated at an industry standard 1 m away from the driver. Outside of the speaker stand, the speaker under test, the reference microphone, microphone stand, and cabling, the room should be free of any unnecessary items.

3 Sources of Error

The soundcard, reference microphone, microphone placement, room acoustics, and items in the room all contribute to the error in a measurement system. It is unrealistic for most engineers to have access to a test system that is completely free of controllable nonlinearities, especially errors from room acoustics. Room acoustic errors include room modes and comb filtering. However, this level of precision is normally not necessary for real-world applications. Given that most consumers use products in very poor acoustic environments, squeezing the last percentage point of error out of a measurement system will generally experience diminishing returns. This application note covers a practical method to optimize the measurement environment to deliver results that allow the user to capture workable frequency response measurements.

4 Equipment Needed

- Computer capable of running measurement software
 - A computer capable of running audio test software is needed. The software featured in this note, Room Equalizer Wizard ([REW](#)) – used with written consent, is cross-platform compatible.
- Measurement software
 - Audio test software, capable of producing a frequency sweep, calibrating SPL and gain levels, and showing a frequency response plot are necessary for frequency response measurements. Software that provides loopback testing for audio interfaces and enables calibration files (audio interface and microphone) increase the accuracy of the system, and are desirable features. There are many software packages that offer this functionality. REW is used in this paper, available for free online.
- Reference microphone
 - Reference microphones are a unique type of condenser microphone that have a highly linear SPL response over the audio frequency band. All have unit-to-unit variation in sensitivity that varies with frequency, creating a source of frequency response error. For professional setups, individual reference microphones are calibrated to remove unit-to-unit variations. Average calibration files are available online for some commonly available reference microphones which provide a best-guess calibration without the additional resource investment of getting a microphone calibrated. Note that averaged calibration files may introduce more error into the system than was present without the calibration file.

- Audio interface
 - An audio interface is required to connect the reference microphone to the computer. A small 2 in x 2 out USB audio interface, which features a 24-bit, 96-kHz sampling rate DAC, and two input channels which accept both XLR and 1/4 inch (line) inputs. Depending on your reference microphone, phantom power (± 48 V) may be required to power the microphone.
- Miscellaneous
 - 1/4-inch and XLR cables are needed for the audio interface testing and reference microphone connections, respectively. A microphone stand is needed for the reference microphone. A speaker stand is required for most test setups.
- System under test
 - Finally, the audio system under test is needed, with any necessary power supplies, audio input interface, and the ability to have computer-generated audio output as an input to the audio system.

5 Combining Near- and Far-Field Measurements

Simulating free-field measurements without an anechoic chamber is possible by combining the low-frequency response of a near-field measurement with the higher frequency response of a gated far-field measurement in a non-ideal room. Software tools merge separate measurements and also adjust impulse response (IR) windows of a measurement after the measurement has been taken. This document demonstrates capturing these measurements for an example system.

6 Simulated Anechoic Measurements

6.1 Near-Field Measurement

Near-field measurements are taken where the distance between the driver and the microphone is as small as safely possible, that is, almost touching the dust cap of the driver diaphragm. Technically, Keele defines near field as microphone placement where the distance between microphone and driver is less than or equal to $0.11 \times a$ (a = piston radius of a given driver). Frequency response measured with near-field microphone placement will mirror performance of the system in free-field conditions (anechoic chamber) for frequencies where $ka \leq 1$, where $k = 2 \times \pi \times f/c = 345$ m/s (velocity of sound) and a = piston radius of the driver (Keele 155-156).

A guideline from *Introduction to Electroacoustics & Audio Amplifier Design* is that for a given driver diameter in inches, the piston radius is equivalent to the driver diameter in centimeters (Leach 21). For the system under test, the driver is a 2 inch full range, and the piston radius is about 2.2 cm. The approximation from the Leach text provides a workable approximation for the piston radius (estimated 2 cm).

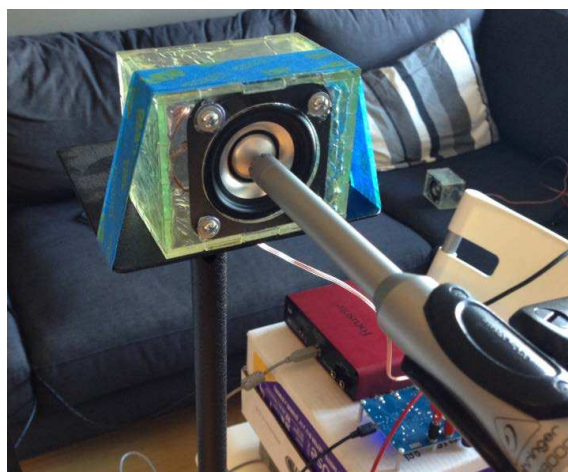


Figure 1. Example of Near-Field Microphone Placement

6.2 Far-Field Measurement

Fresnel diffraction effects will show up as frequency-dependent SPL variation in a frequency response measurement taken when microphone placement is less than 6 times the piston radius. To eliminate Fresnel diffraction effects, far-field measurements are taken where the distance between driver and microphone is greater than 6 times the piston radius. Fresnel diffraction does not have a significant effect on sound pressure levels when microphone placement is greater than this distance (ALTA 3). Note that for the near-field measurement, the extreme proximity of the driver to the microphone will help mitigate Fresnel diffraction effects on SPL (Keele 156). The audio industry has standardized around a 1-meter distance between the driver and the microphone for the far-field measurement, as a general rule. The microphone should be placed on the same axis as the tweeter to avoid high-frequency directionality effects.



Figure 2. Example of Far-Field Microphone Placement

6.3 Reflections and Comb Filtering

Reflections from various surfaces in the room will show up as time delayed and amplitude-reduced impulses of the original signal. Audible reflections as a product of the room causes comb filtering which shows up in the frequency response as constructive and destructive interferences, and has a comb-like effect on the frequency response.

There are two strategies to minimize the effects of reflections. One is to remove the reflections (change the room), and the second is to minimize the reflections with optimal speaker/microphone placement and impulse-response windowing. [Figure 3](#) shows an example of comb filtering in a far-field response with no impulse-response windowing applied.

6.4 Optimal Speaker Placement

To minimize room reflections, the speaker should be placed on a stand and raised roughly to the center of the height of the room. For 10-ft tall ceilings, we want the speaker driver to be as close to 5 ft as possible. This is not possible with all speaker stands and setups, however, note that it is easiest to minimize the effect of early reflections with this technique. As the height off the floor decreases, the time it takes for the reflection to appear at the microphone decreases, requiring tighter windows to minimize comb filtering in the measured response.

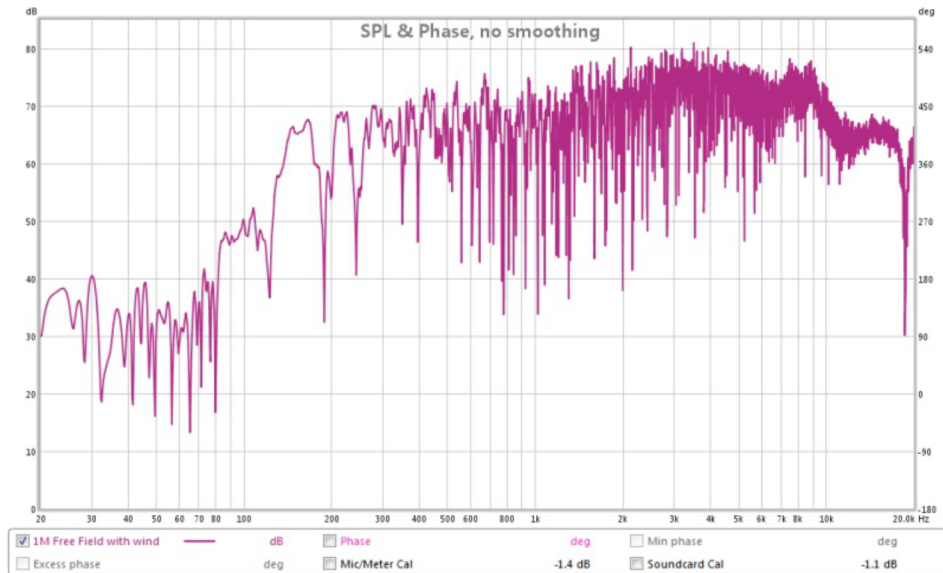


Figure 3. Comb Filtering with no IR Window

6.5 Windowing

Figure 4 shows an example impulse response captured from a sweep measurement in REW v5. The original impulse is shown on the far left, with the y axis representing the magnitude and the x axis representing the signal over time. Each one of the reflections shows up in the impulse response waveform as time delayed and magnitude-reduced versions of the original impulse.



Figure 4. Impulse Response

6.6 Adjusting the Impulse Response Window

Figure 5 and Figure 6 show two window lengths and the effect of window length on frequency response. The first window has a width of 8 ms, and allows the impulse as well as some early reflections into the frequency response. Take note of the comb filtering present throughout the measurement, especially compared to the second frequency response graph. The second window has a width of 2.5 ms, and allows only the initial impulse to effect the frequency response plot. Notice the removal of most of the comb filtering. Note that using a very short window removes the reflections from the room, but also removes baffle diffraction effects, painting a somewhat inaccurate picture of the speaker performance. One adjusts the window lengths depending on multiple factors, including the room characteristics, the driver/system under test, and the desired measurement range.

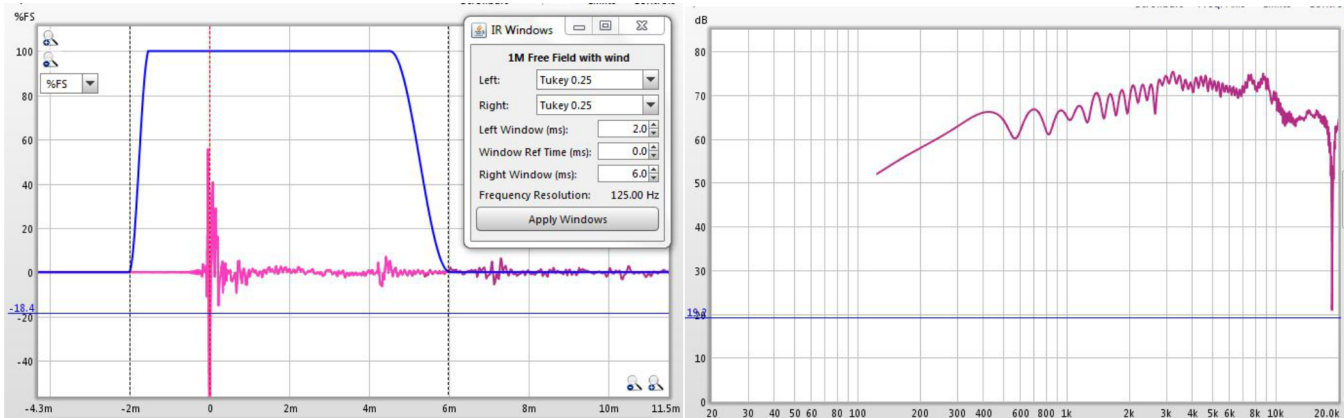


Figure 5. IR Window and Frequency Response - 8 ms Window

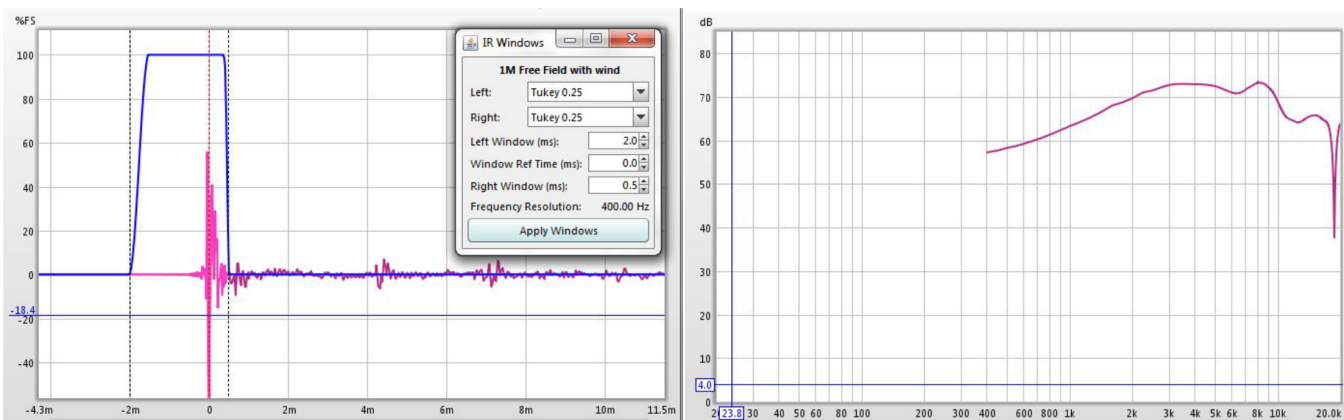


Figure 6. IR Window and Frequency Response - 2.5 ms Window

6.7 Merging the Measurements

As previously defined, the near-field frequency response is accurate for frequencies equal to and less than $ka = 1$, where $k = 2 \times \pi \times f/c$ (345 m/s) and $a =$ piston radius (0.022). Given $r = 0.022$ m, solving for f gives us $f = 2495.94$ Hz. Therefore, the near-field measurements are roughly equivalent to free space measurements for frequencies up to 2.5 kHz. Our merge point for the two measurements should be around 2.5 kHz.

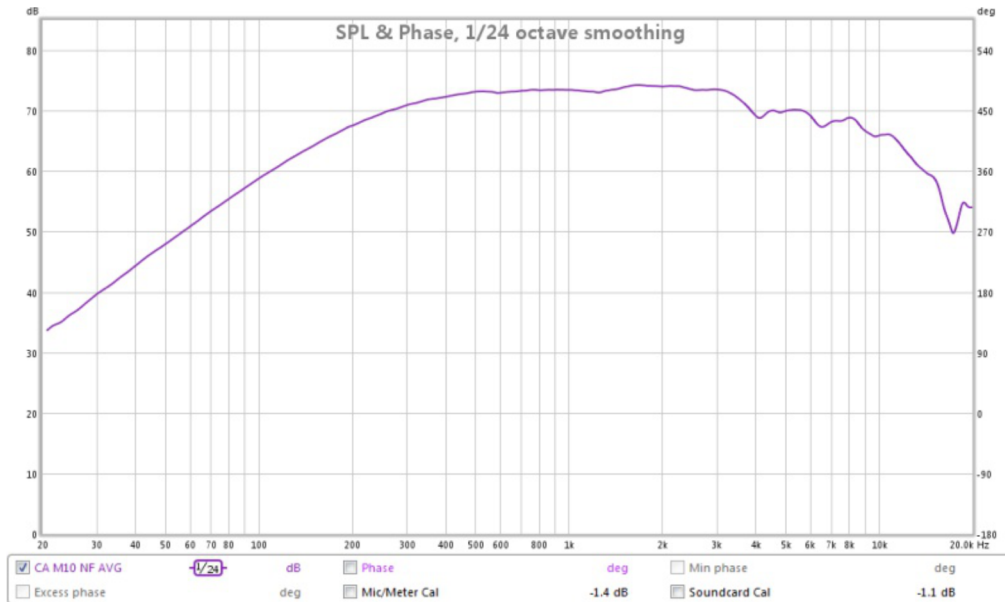


Figure 7. Near-Field Frequency Response

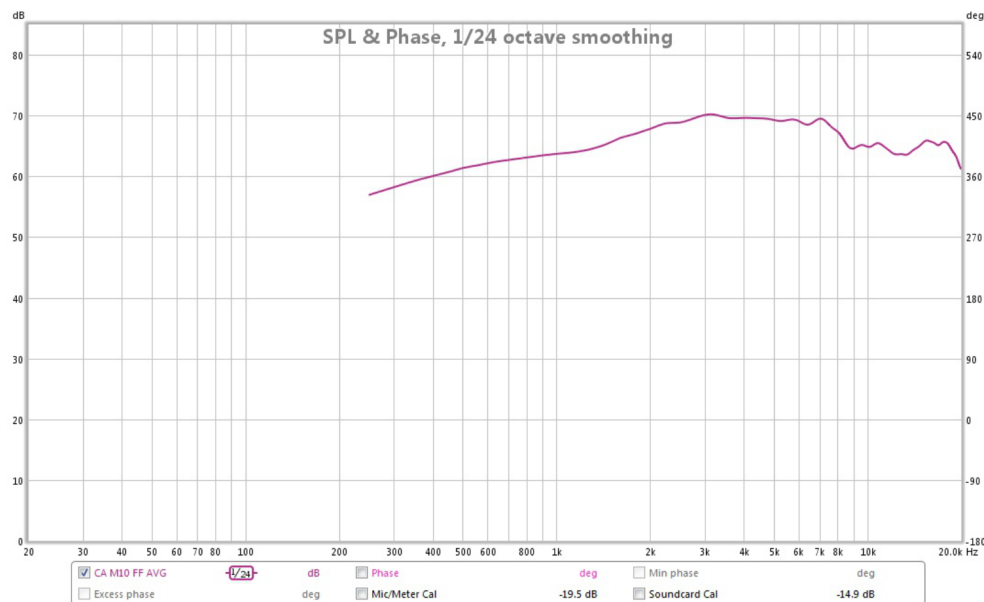


Figure 8. Far-Field Frequency Response

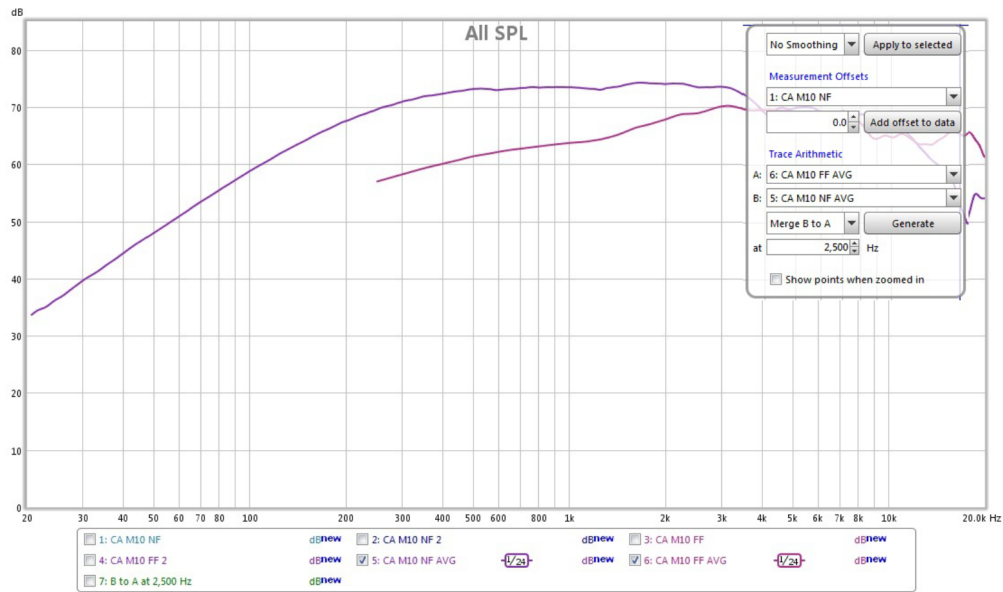


Figure 9. Near- and Far-Field Frequency Responses, Merge Dialogue

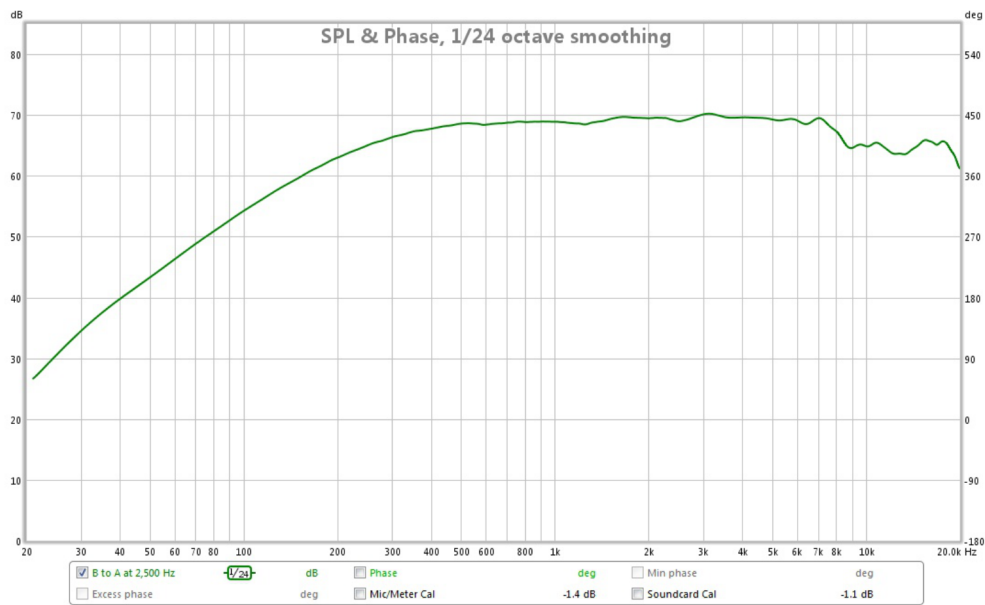


Figure 10. Merged Frequency Response

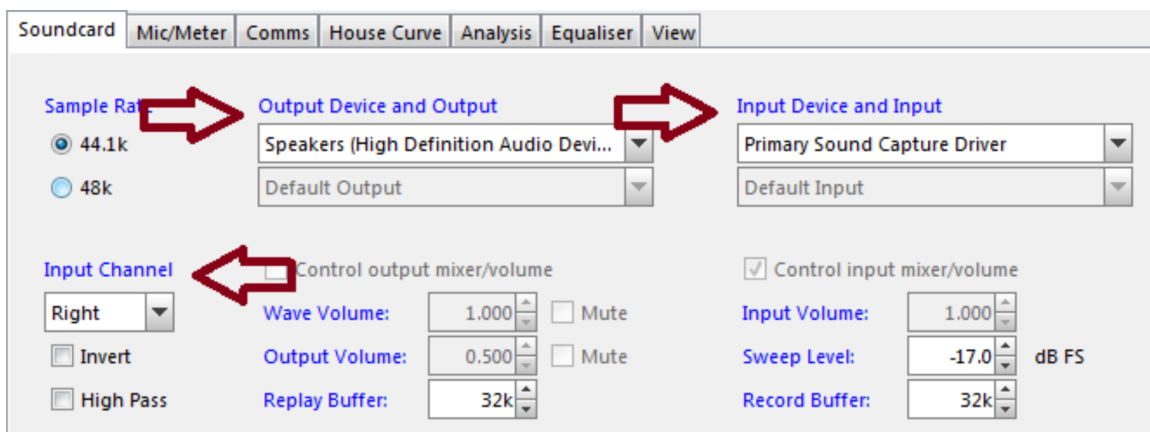
7 Frequency Response Measurement Walkthrough

7.1 Equipment

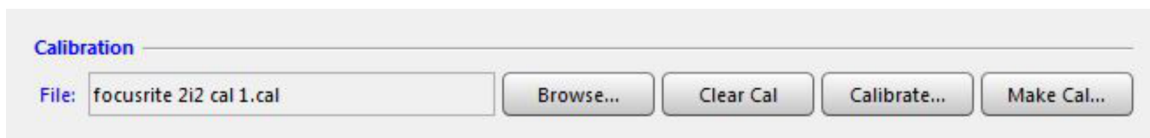
- PC: Microsoft® Windows® 7, 64 bit
- Software: REW v5
- Audio interface: Focusrite Scarlett 2i2 (input) and TPA3116D2 EVM (output)
- Reference microphone: Behringer ECM8000 Uncalibrated
- Misc: speaker stand, 1/4 inch instrument cable, XLR cable, DC power supply

7.2 Procedure

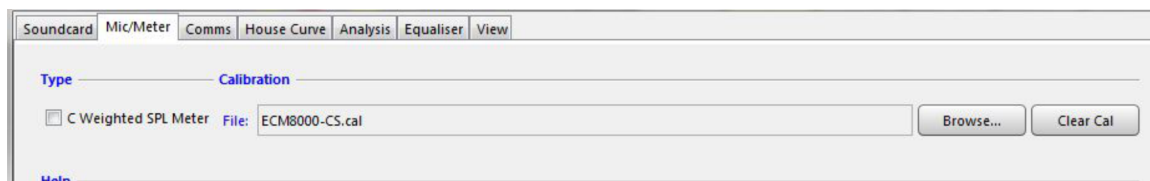
- Step 1. Setup microphone, speaker stand, and room as previously discussed. Set microphone and speaker placement for either near- or far-field measurement, and then reset for the opposite measurement at Step 9.
- Step 2. Open REW v5.
- Step 3. Edit preferences for correct sound input and output, as well as input channel.



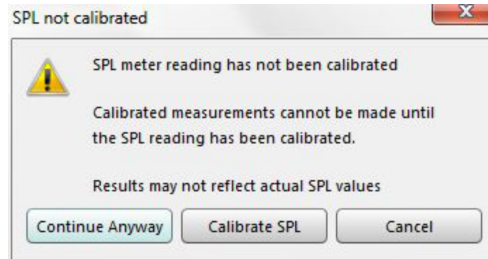
- Step 4. Perform soundcard loopback calibration testing if you have not yet made a calibration file. Click the **Calibrate...** button to start the calibration. You will need a 1/4 inch instrument cable for this test.



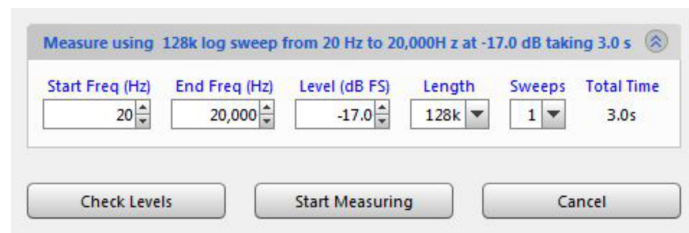
- Step 5. If desired, add a microphone calibration as well.



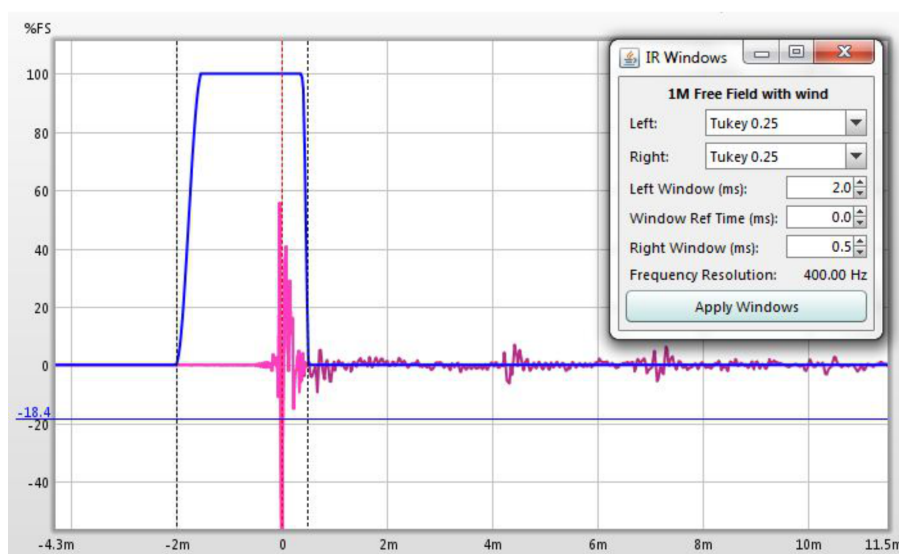
- Step 6. Click **Measure** to start a new measurement. Note that a dialogue comes up asking for SPL calibration. If you have an SPL meter, you may calibrate REW for absolute SPL. If you do not have an SPL meter, you can click **Continue Anyway** to make relative SPL measurements. All graphs in this paper use relative SPL measurements.



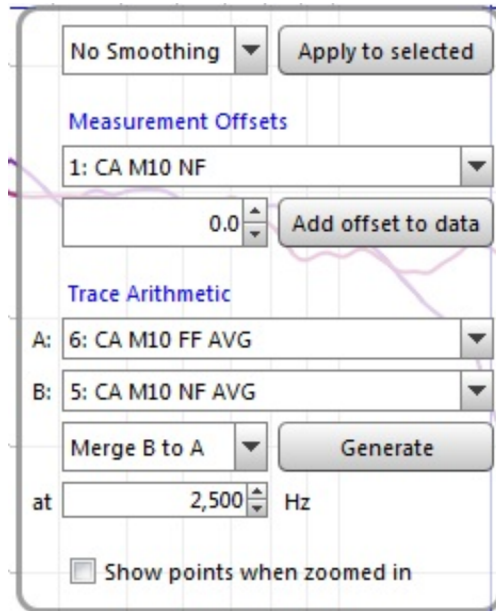
- Step 7. Make sure that the start and end frequencies, level, sweep length, and number of sweeps are all set properly. For this document, 512k sweeps is used for all measurements. Next, check the levels and make sure that the microphone gain is set appropriately. If the level is too hot or cold, adjust the preamp gain on your audio interface until REW says *Level OK*.



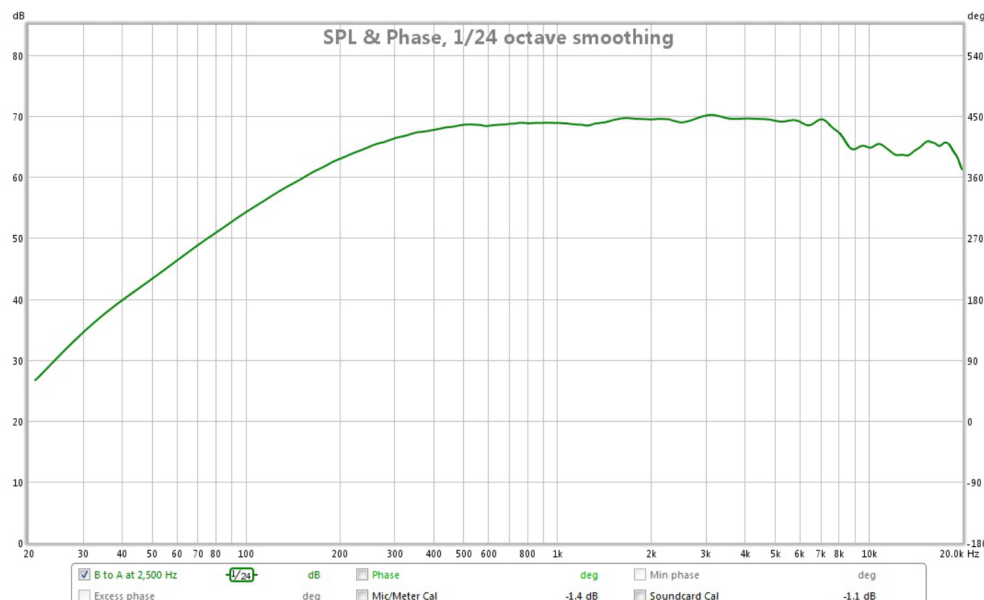
- Step 8. Click **Start Measuring** to measure your first frequency sweep. Rename the title to either near or far field (NF/FF) for ease of use.
- Step 9. Reset the microphone placement for the opposite measurement, either near or far field.
- Step 10. Return to Step 6 and repeat through Step 8 for the second measurement.
- Step 11. Setup windowing on your far-field measurement. With the far-field measurement highlighted, click on IR windows to bring up the IR dialogue. Click on *Impulse* to get a graph of the impulse response, and adjust the graph limits as necessary. Adjust the impulse response window to minimize room reflections.



- Step 12. With windowing on the far-field measurement set, click on *All SPL* to generate a graph of all traces on the same screen. Click on **Controls** to start merging the two responses together. Under *Trace Arithmetic*, set trace A to the far-field measurement with IR windowing, and trace B to the near-field measurement. Choose *Merge B to A* in the dropdown, and then enter the calculated crossover frequency in the text box. Click **Generate**.



- Step 13. Click on *SPL & Phase* to return to a single trace view. Highlight your new generated trace. Click on *IR Windows* and reopen the window to allow frequency resolution down to 20 Hz. This is your combined frequency response that simulates an anechoic chamber measurement.



8 References

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5. Room Equalizer Wizard (REW) (<http://www.roomeqwizard.com/>)

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