Audio Circuit Testing

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Introduction

This application note explains how to measure the performance of an audio amplifier using the SA/RA Series Frequency Response Analyzer sometimes also called a Vector Network Analyzer. After an introduction to the measurements, this document will show how to setup the Frequency Response Analyzer and how to perform the measurements. Many network analyzers will not go low enough in frequency to test audio circuitry which is an advantage to the SA and RA Series Frequency Response Analyzers.

Measurements

The following measurements are outlined in this application note:

- Frequency Response of each amplifier stage.
- Input impedance of the amplifier.
- Effect of tone controls.
- Input to output phase shift.

In engineering and in manufacturing it is important to know that the audio circuits in an amplifier are performing as designed. The frequency response plot, or transfer function, with magnitude and phase gives us a complete picture of how an amplifier circuit performs over the specified frequency range. The following are some system parameters that are typically measured and why they are important. We will be demonstrating how to make these measurements using the SA/RA Series Frequency Response Analyzer.

Frequency Response. The frequency range over which the amplifier system is to operate is usually a design parameter. Typically, the bandwidth of an audio product is defined as the frequency point at which the gain falls to –3dB of the desired pass band gain. It is important to design a system that amplifies signals over a specified bandwidth and rejects out of bandwidth signals to limit system noise or to prevent unwanted, out of band signals from causing interference.

Input Impedance. The input impedance *of an amplifier* is the input impedance "seen" by the source driving the input of the amplifier. If it is too low, it can have an adverse loading effect on the previous stage and possibly affecting the frequency response and output signal level of that stage. Single ended line inputs of most amplifiers are high impedance to minimize loading.

Filters. Filters of all types are quite common in audio circuitry. A phono preamp usually rolls off below 20 Hz to prevent sub-sonic noise from getting to sub-woofers. Tone controls are another type of common filter in audio equipment. Tone controls allow the frequency response of the audio system to be adjusted to compensate for the response of speakers and their enclosures or the listening room, or to simply provide a more pleasing sound It is important to verify that these filters are performing as designed.

Phase. The phase of the output signal relative to the input signal over the frequency range is important, especially in audio systems. Any significant relative phase shift or phase mismatch between the left and right audio channels will cause phase distortion in the audio program material, resulting in an unpleasant listening experience.

Measurement Setup

The measurements below are performed on an existing audio amplifier. We will assume that the Frequency Response Analyzer (FRA) is connected to a PC that is running SA/RA Series FRA 5.50 software.

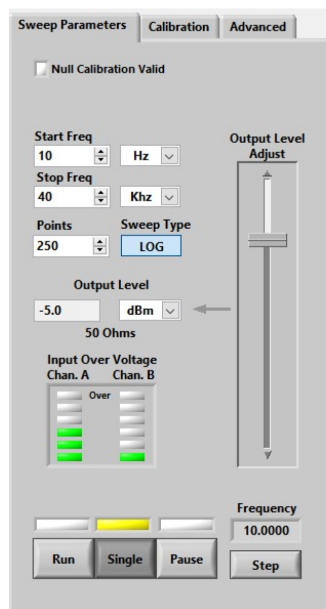


Figure 1
Sweep Parameters

For these audio measurements we perform a logarithmic frequency sweep from 10 Hz to 40 kHz and start with an output level of -5 dBm, so that we do not over drive the amplifier input. You also want to make sure both input level meters show several green bars, to be sure there is enough signal for the measurements.

Starting with the **Sweep Parameters** tab in the Setup section on the right side of the Main Window, enter the appropriate values into the boxes. Note: the Output Level is set by moving the slider on the right. If a red bar appears on either input level meter, decrease the output level and run the test again.

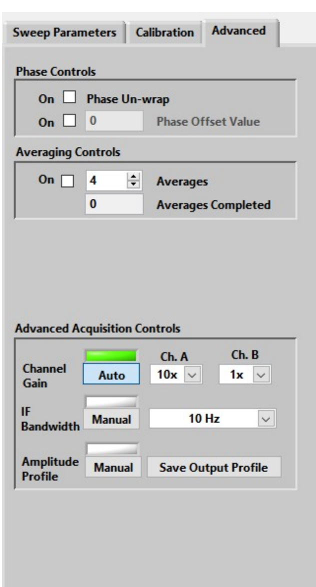


Figure 2
Advanced Settings

Next select the **Advanced** tab and enter 10 Hz as the IF bandwidth. As a rule of thumb, IF bandwidth should be equal to or less than the lowest sweep frequency. Keep in mind, the lower the IF Bandwidth the longer the sweep will take due to the calculations required. Likewise the number of **Points** on the **Sweep Parameters** tab will also cause the sweep time to increase as the number of points is increased, again due to the number of calculations involved.

Input Impedance

The first test will be to check the Input Impedance of the preamplifier stage. To conduct the Input Impedance test, follow the diagram in Figure 3. The test setup uses a 50 ohm terminator at the junction of the Output and Input B on the Frequency Response Analyzer. It is important to note, the output of the FRA must be terminated with 50 ohms to insure the output voltage levels are calibrated. There is a second resistor R_L across Input A of the Frequency Response Analyzer. This resistor (R_L) develops a current which is used by the FRA in determining the network characteristics. This is why the FRA ground is not directly connected to the amplifier ground.

This test treats the input of the amplifier as a "Black Box" reading both voltage and current through the network. In this case the network is only resistive with some parasitic capacitance. We also know the values of the components because we have access and can measure them.

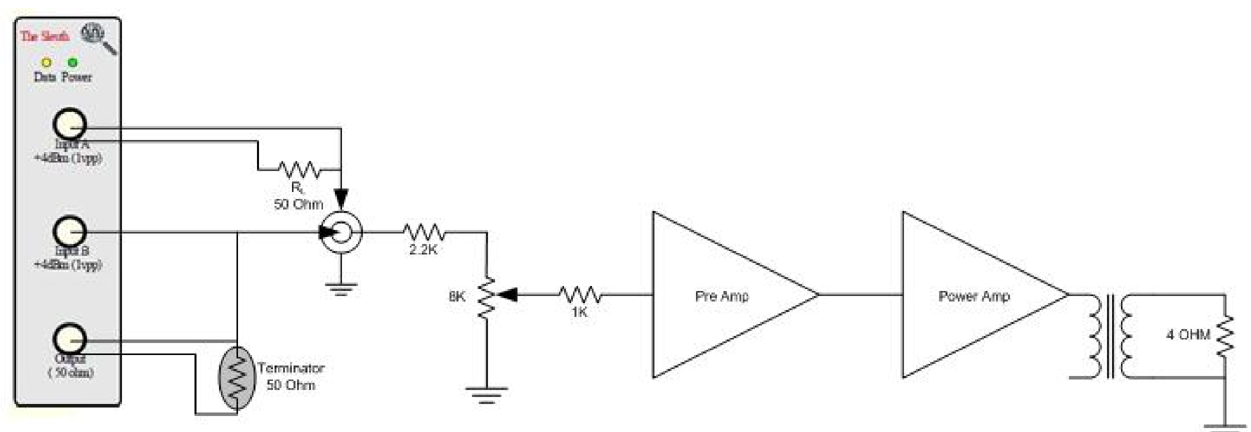


Figure 3
Input Impedance Test Setup

Select "**Impedance (Magnitude, Phase)**" In the Graph Mode box in the center of the FRS window. When ready to run the test, click the "**Run**" button in the FRS window.

The test will begin immediately and the display will begin to draw the waveform. The Red waveform is the Impedance Magnitude in ohms and the Blue waveform is the phase. The amplifier we used for this test apparently has an input impedance of less than 13.36 K ohm which decrease as the frequency approaches 20 KHz. At the same time the phase of the input changes from about 0 degrees to nearly -30 degrees at 40 KHz.

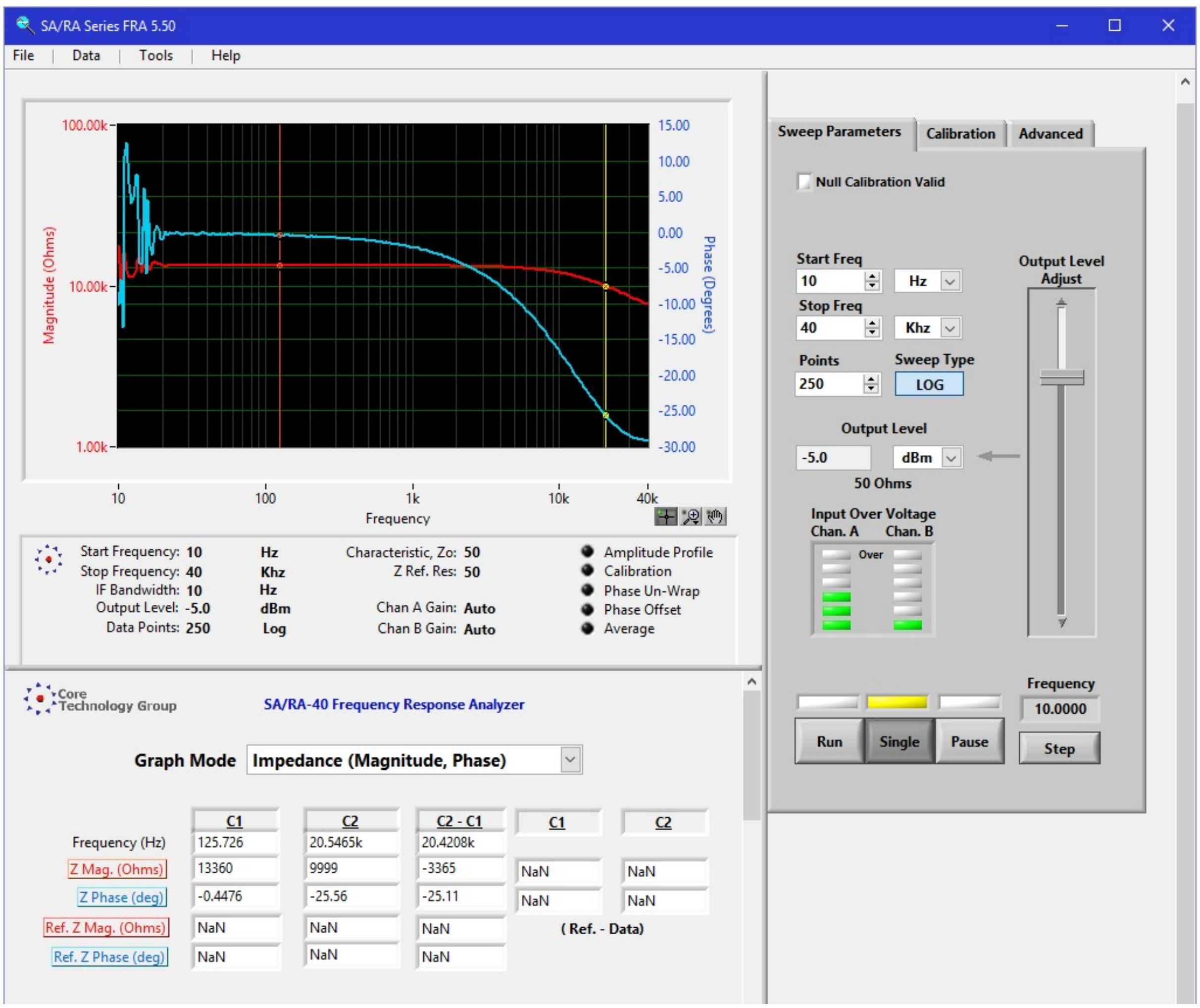


Figure 4
Input Impedance Measurement

The Frequency Response Analyzer has two cursors which can be positioned over the graph to find details of the waveforms. The details are displayed in the lower portion of the screen. In this case, the Red cursor (C1) is moved to 125.726 Hz. At this position the impedance is 13.36K Ohms.

Looking at Figure 4, the impedance (Red) graph begins to roll off at around 8 KHz. This roll off is caused by capacitance in the circuit. We positioned the Yellow cursor (C2) over the sloping portion of the graph. Under C2 on the lower portion of the screen the frequency (F) is 20.5465 Khz, the impedance (Z Mag) is 9,999 ohms and the phase (Z Phase) is -25.56 degrees. From this we can calculate the capacitance by using the equation:

$$C=1/(2\pi F(Z\ Mag)(\sin(Z\ Phase))$$

Where:

- C is the capacitance in Farads
- F is the frequency in Hz
- Z Mag is the impedance in Ohms
- Z Phase is the phase angle at this frequency (Ignore the sign)

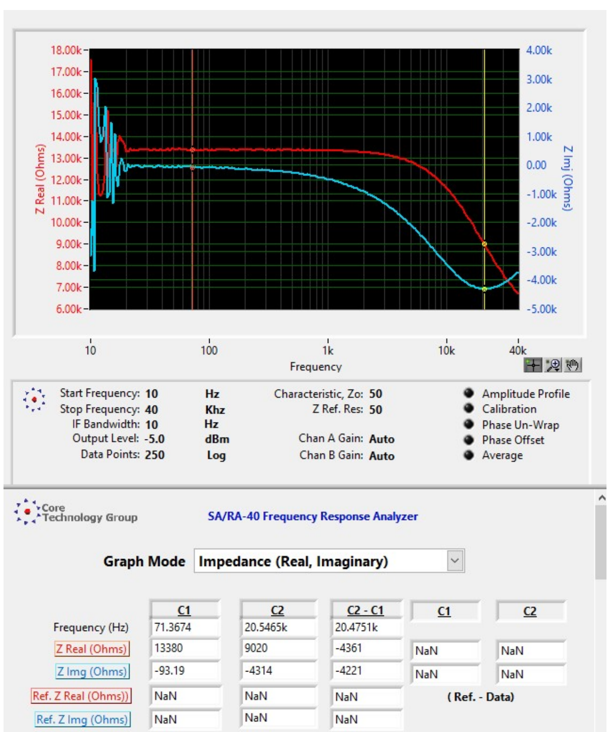


Figure 5
Impedance, Real & Imaginary

From this calculation the capacitance is 1.87^{-9} or 1,870 pF.

By changing the Graph Mode to "**Impedance (Real, Imaginary)**" the actual capacitive reactance (X_C) is displayed under C2 as Z Img, shown in Figure 5. This saves having to calculate the capacitive reactance or imaginary impedance. The equation then reduces to:

$$C=1/(2\pi F(Z\ Img))$$

Where:

Z Img is the capacitive reactance.

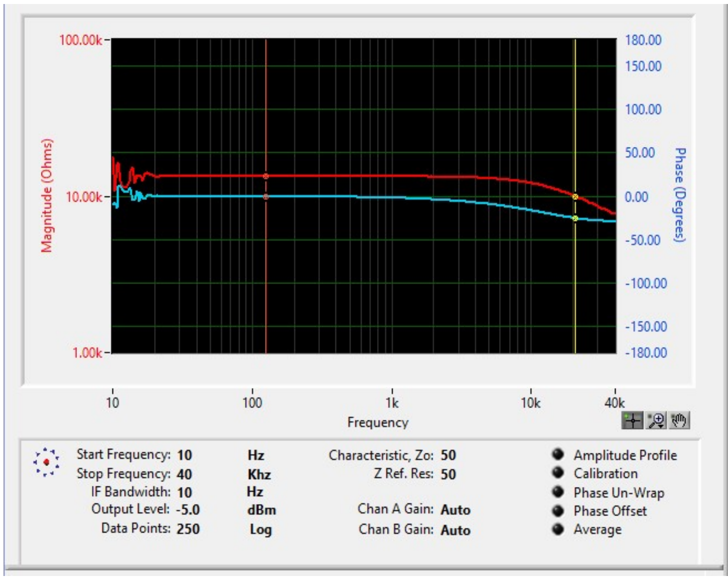


Figure 6
Display with Phase Scale Changed

We can adjust the range of the vertical (Y) axis of Magnitude or Phase to see more or less information. In this example, we change Graph Mode back to "**Impedance (Magnitude, Phase)**" where the phase scale is from +15 degrees to -30 degrees.

To change the vertical scaling, click on the end numbers and type in the desired value. In this case we clicked on 15.00 degrees and entered 180 degrees, then clicked on -30 degrees and entered -180 degrees. We can use this feature to adjust the scale in or out as required. Figure 6 shows the resulting phase information with the range changed.

Note: The information displayed in the box directly under the graph shows the current setup of the Frequency Response Analyzer.

Input Frequency Response

The Frequency Response Analyzer allows us to view the frequency response of the amplifier at different stages or across the entire amplifier. To measure frequency response will require changing the connections to the amplifier. Use the wiring in Figure 7 as a guide to connecting the FRA to an amplifier. To make it easy to measure between stages we connect an oscilloscope probe to Input B. Click the "**Run**" button on the main screen to measure the frequency response.

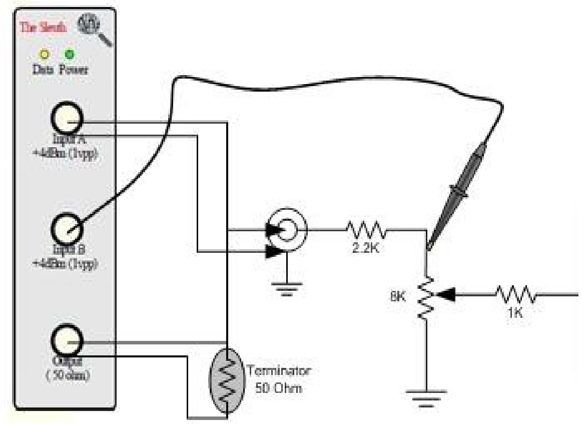


Figure 7
Input Frequency Response

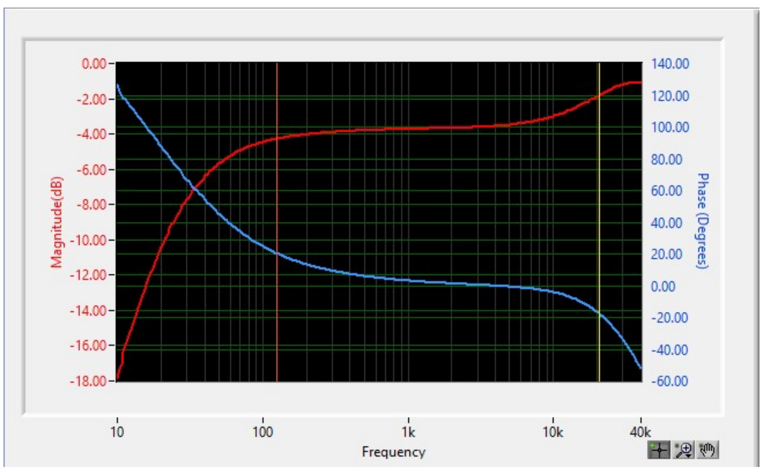


Figure 8
Input Frequency Response

The Magnitude (Red) trace on the graph in Figure 8 shows the frequency response at the input stage of the amplifier. The 3 db rise from 10KHz to 40KHz is caused by the 1,870 pF capacitance we saw in the input stage reacting with parasitic inductance. The Phase (Blue) trace is the phase of the signal across the audio spectrum which corresponds to the frequency response.

Preamp Frequency Response

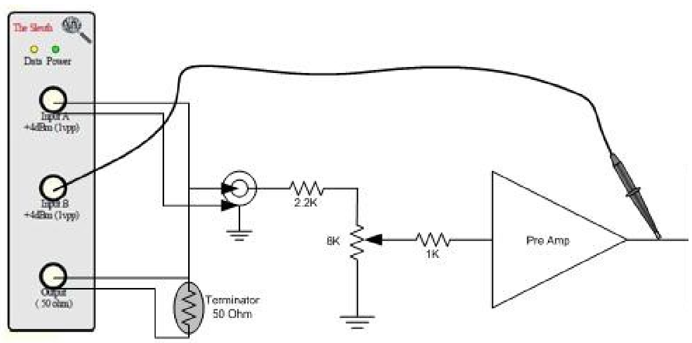


Figure 9
Preamp Frequency Response

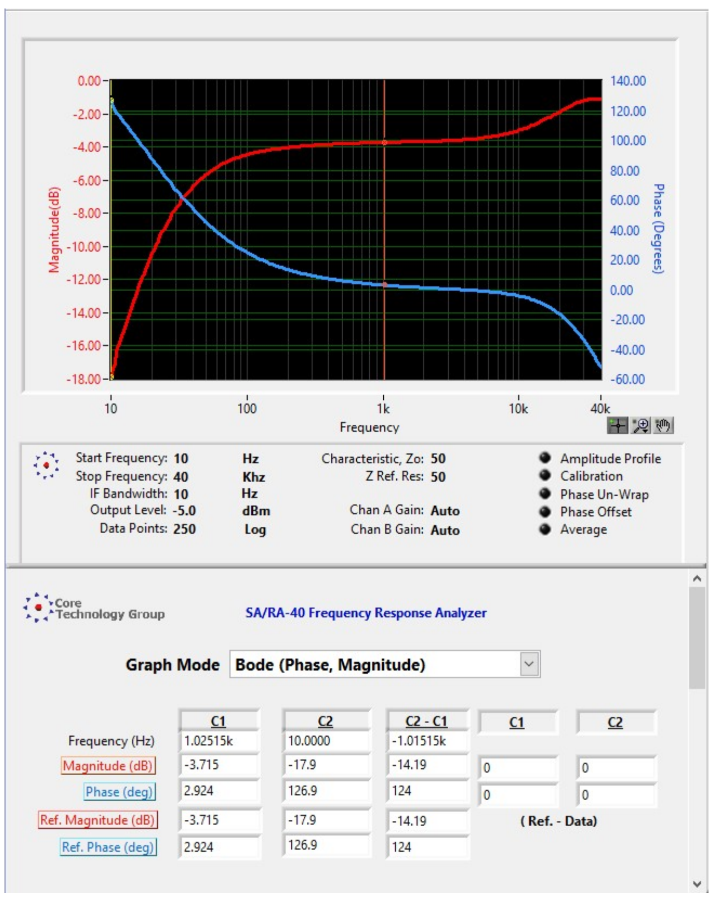


Figure 10
Preamp Frequency Response Measurement

Without changing the input connections, simply move the oscilloscope probe to the output of the Preamp stage. Click the "**Run**" button on the main screen to conduct this test.

The Preamp frequency response is virtually identical to the Input frequency response, the phase is also unchanged through the preamp stage.

The FRA software has the ability to save the Current Test as a Reference. We used the menu **Data>Current Test → Reference** to make the Input Frequency Response test the Reference for comparison to the Preamp Frequency Response test. The graph in Figure 10 shows both waveforms overlaid.

In Figure 10 the Red cursor (C1) is positioned at 1 Khz. to measure the gain at this frequency. Looking at the data displayed under the graph, in the C1 column, the Magnitude is -3.715 dB. The Reference Magnitude is also -3.715 dB. Therefore, at this frequency both stages are truly identical.

Note: The cursors remain in the same position as the Graph Mode is changed.

Power Amp Frequency Response

Again, without changing the input connections simply move the oscilloscope probe to the output of the amplifier as shown in Figure 11. Click the "**Run**" button on the main screen to measure the frequency response.

We did not clear the Reference display when running this test. Therefore, the test results are shown along with the previous Preamp test results.

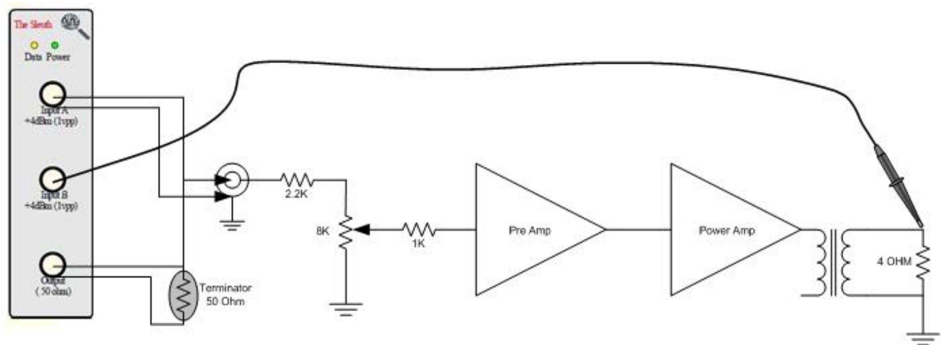
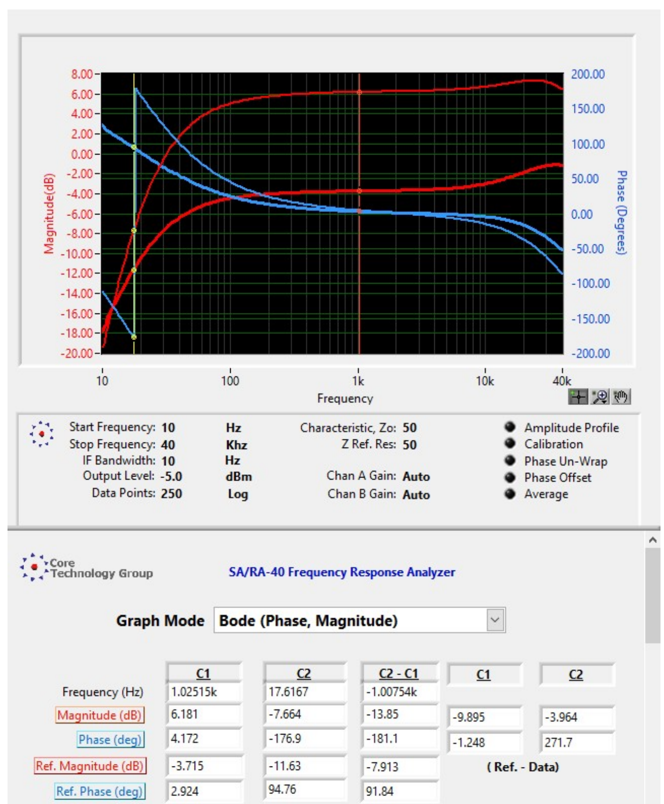


Figure 11
Output Frequency Response Measurement

Unlike the Input and Preamp stages, there are differences in the Power Amplifier stage. There is an increase in gain (Red graphs) and there is also a change in phase shift (Blue graphs) across the audio spectrum.

Cursor 2 is positioned where the phase shift is minimum. The data displayed below the graph shows the frequency under C2 as 17.617 Hz. The phase shift at this frequency decreases below -180 degrees which causes the graph to continue at +180 degrees; simply a sign change.

Note: There is a control under the **Advanced Setup** tab called **Phase Un-wrap** that will remove the step sign change and will keep the phase displayed as a continuous line.



	C1	C2	C2 - C1	C1	C2
Frequency (Hz)	1.02515k	17.6167	-1.00754k		
Magnitude (dB)	6.181	-7.664	-13.85	-9.895	-3.964
Phase (deg)	4.172	-176.9	-181.1	-1.248	271.7
Ref. Magnitude (dB)	-3.715	-11.63	-7.913		
Ref. Phase (deg)	2.924	94.76	91.84		

Figure 12
Power Amp Frequency Response

Looking at the Magnitude graphs in Figure 12, we see an increase in gain. We measure the gain change by moving a cursor to a desired frequency. In this case, the Red cursor (C1) is positioned at 1 KHz. The data below the graph shows that the gain changed from -3.735 dB to +6.181 dB; a 9.916 dB increase.

Filter Frequency Response

The amplifier in test has a three band tone control section between the Preamp stage and the Power Amplifier stage. To see how the tone control effects the frequency response, we leave the probe connected to the output and adjust the mid-band (1 KHz) tone control to minimum. The Power amplifier test was made the Reference and another test was "**Run**".

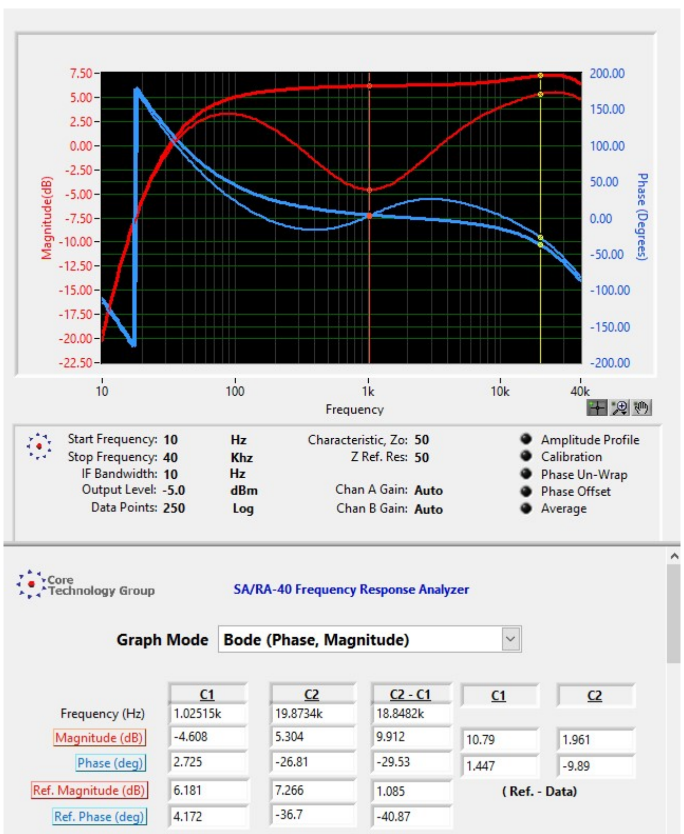


Figure 13
1 Khz Filter Frequency Response

Figure 13 shows the effect of the mid-band tone control compared to the normal output frequency response. Here we measure an attenuation of 10.789 dB at 1 Khz. This tone control also effects the frequency response at 20 KHz. By moving Cursor 2 to 19.87 KHz, we measure 1.962 dB attenuation.

We also see a change in the Phase around 1 KHz which is expected due to the 1 KHz filter response. If desired, the phase change can be measured bu moving a cursor and reading the data.

Note: The number of Points in the **Sweep Parameters** tab defines the resolution of the waveform. If finer resolution is desired, increase the number of points. Increasing the number of points will also increase the time it takes to make the frequency sweep.

Summary

This application note demonstrates how to make measurements of a typical audio circuit. When designing an amplifier, engineers make theoretical calculations and simulations regarding circuit performance. These calculations can be verified with a frequency response analyzer. In addition, the data gathered can be used by the engineers to improve simulation models. In production, system performance can be quickly verified against a saved test, to see how manufacturing variations and component tolerances are effecting circuit performance. This Application Note shows only a small portion of the abilities of the frequency response analyzer in testing typical audio circuits.

In short, the frequency response analyzer is an essential tool for engineers to verify their designs and to insure component variations do not render performance outside product specifications.