VOICE COIL
THE PERIODICAL FOR THE LOUDSPEAKER INDUSTRY

Article prepared for www.audioXpress.com

CLIO 8 *fw* Electroacoustic Measurement System

By Joe D'Appolito

CLIO 8 fw is the newest electroacoustic measurement system from Audiomatica. It consists of the CLIO 8 fw software and the new FW-01 Firewire Audio Interface. The FW-01, which is the latest measurement hardware offering from Audiomatica, is a complete two-channel professional A-to-D and D-to-A front end for a PC. The 24-bit 192kHz ADCs provide state-of–the-art measurement capability.

The FW-01 sets new hardware precision standards for the CLIO electroacoustic measurement system and connects to your computer via an IEEE-1394 (Firewire) link. It can also be powered by this link for easy portability. The FW-01 is equipped with instrument grade balanced input and output analog circuitry with an exceptionally wide dynamic range. The balanced XLR inputs have a switchable phantom power supply that allows connection of microphones available from Audiomatica, in addition to a wide range of professional balanced microphones from other vendors.

Hardware Specifications

The FW-01 audio interface contains a two-channel signal generator and two channels of data acquisition called the analyzer. Specifications for the signal generators and the data acquisition channels are given in ***Tables 1*** and ***2,*** respectively. The FW-01 connects to your PC via an IEEE 1394 link which, depending upon your PC, can also power the unit. Alternatively, you can use an external 12V DC power supply capable of delivering 1A to power the FW-01.

Table 1 FW-01 Generator Specifications

Two channels: 24-bit sigma-delta D/A converter
Frequency range: 1Hz-90kHz
Frequency accuracy: >0.01%
Frequency resolution: 0.01Hz
Output impedance: 660Ω
Max output level (Sine): 17dBu (5.5V RMS)
Attenuation: 0.1dB steps to full mute

Table 2 FW-01 Analyzer Specifications

Two channels 24-bit sigma-delta A/D converter
Sampling frequencies: 192kHz, 96kHz, and 48kHz
Input range: −40 to +40dBV
Max input acceptance: +40dBV (283Vpp)
Input impedance: 128kΩ (5.6kΩ microphone)
Phantom power supply: 24V

The Signal Generator

CLIO 8 provides a rich range of signal types that supply the stimulus for the many measurement analysis modes CLIO supports. The various signals produced by CLIO's programmable signal generator are described here briefly.

Sinusoids: The signal generator can output sine waves of any frequency in the range of 1 to 90kHz with a resolution of .01Hz. The signal can be continuous or played as a burst. In the burst mode the time on and time off can be specified. By selecting "FFT Bin Round" in the sinusoidal dialog box, the sine wave frequency will be approximated to the nearest FFT bin to reduce spectral leakage in any subsequent FFT analysis.

Two Sinusoids: Two sinusoids of user selectable frequency and amplitude can be generated. This signal is especially useful for two-tone intermodulation distortion analysis.

Multitones: The multitone signal consists of 31 sinusoids centered on the 31 octave bands of classical RTA analysis. From the Multitone dialog box it is possible to select all 31 sinusoids or any subset of them. You can select multitone signal lengths of 4K to 128K to match corresponding FFT lengths in the FFT/RTA measurement analysis mode to be described later.

White Noise: The signal generator can output a continuous white noise signal.

MLS: CLIO produces MLS (maximum length sequences) signals of length 4K to 256K before repeating. With a corresponding FFT length of 256K (actually 262144) and a sample rate of 48kHz, a measurement resolution of 0.183Hz is possible.

Sinusoidal Chirps: Chirps are sine waves varying continuously in time over a specified frequency range. Full spectrum log chirps are used for frequency response analysis in the MLS/Log Chirp analysis mode. Alternatively, lower and upper frequency limits for the chirp can be set in the Chirp dialog box. Both linear and log chirps versus time are available in lengths from 4K to 256K. They are also useful in the FFT/RTA analysis mode.

Pink Noise: Pink noise of signal lengths 512 to 128K are available for RTA analysis.

All Tones: All tones signals are a sum of sinusoids of frequencies corresponding to each frequency bin of an FFT of given length and sampling frequency. For example, at 1024 point FFT at a sampling frequency of 48kHz will have FFT bins 46.875Hz apart. The corresponding all tone signal consists of 512 sinusoids ranging from 46.875Hz to 24kHz spaced apart by 46.875Hz.

Signal Files: CLIO can play *.wav files that have been saved to disk. The user can also generate *.wav files from the Leq measurement menu (to be described) for later playback and analysis.

Measurement Analysis Control Panels

From CLIO's opening screen the user can select one of eleven measurement control panels (twelve if you have the CLIO QC option). Seven of these panels control active measurement processes, while the remaining four involve post-processing of measurement data obtained in one of the first seven.

The seven active measurement processes and their associated control panels are:

1. Multimeter
2. MLS and Log Chirp Analysis
3. FFT/RTA Analysis
4. Sinusoidal Analysis
5. Linearity and Distortion Analysis
6. L_{eq} Analysis
7. Wow and Flutter Analysis

The four post-processing control panels are:

1. Waterfall and Directivity Analysis
2. Thiele/Small Parameter Analysis
3. Acoustical Parameter Analysis
4. Wavelet Analysis

I will now briefly describe the function of each control panel. Detailed examples for some of the control panels will be provided in the latter portion of this article with specific emphasis on loudspeaker evaluation.

Multimeter: The multimeter is an interactive, real-time, measuring instrument. The measurement processes available in this panel are:

1. Sound level meter (dBSPL, dBA, dBC)
2. Millivoltmeter (V, dBV, dBu, dBrel)
3. Frequency counter
4. Distortion meter
5. LCR bridge

The multimeter can capture a global reference level for all subsequent measurements. It also has an option for calibrating a microphone when used together with an acoustic calibrator. Sound level is measured in dBSPL when the microphone sensitivity is known. A and C weightings can be applied to the measurement. The distortion option will measure THD or IMD in either percent or dB. The LCR option measures the value of passive components using a set of test leads supplied with CLIO. Finally, the multimeter can operate in a minimized mode slaved to the FFT/RTA control panel. In this state it can monitor a critical parameter such as SPL while making other measurements.

MLS and Log Chirp Control Panel: In this control panel you can measure the impulse response, frequency response, and/or transfer function of any electronic or electroacoustic device. Impedance of these devices can also be measured. The functionality of this panel is particularly suited to loudspeaker response measurements. MLS and Log Chirp signals are the stimuli for these measurements.

When using the MLS stimulus, the system impulse response is computed directly from the measured output of the device under test (DUT). The frequency response is then computed via FFT analysis. The log chirp signal measures the system frequency response from which the impulse response is obtained via the inverse FFT (IFFT). Both stimuli are available in lengths from 4k to 256K.

In each case the corresponding FFT or IFFT is the same length as the signal. Computed spectra can be smoothed with options ranging from 1/12 to ½ octave. Several powerful post-processing functions are available via the MLS processing tool dialog box. Among some of the functions available you can add, subtract, multiply, or divide the current measurement by a complex value or compatible file, use a reference measurement and impedance value to calculate 1m sensitivity in dBSPL/W, or process the current measurement with a user-specified octave band filter.

FFT & RTA Control Panel: The FFT analyzer is perhaps the most powerful and flexible tool CLIO offers. This analyzer determines the frequency content of any input signal using the Fast Fourier Transform (FFT). Any of the many signals CLIO provides as well as live music can be used as stimuli to the DUT. The processed data can be displayed as a narrow band spectrum for detailed analysis.

The analyzer can also operate in an RTA mode, plotting results in 1/3 or 1/6 octave bands. FFT lengths of 512 to 256K (actually 262144) are possible. You can apply Rectangular, Hanning, Hamming, Blackman, Bartlett, and Flat Top windows to the time domain data. You can also apply 1/48 to 1/2 octave smoothing to the computed spectra. Linear and exponential averaging is available. Up to 1000 samples can be averaged in the linear averaging mode.

Two independent channels of frequency domain data can be displayed simultaneously. Alternatively the time data and frequency data of a single signal can be displayed in separate windows. Pressing the "Live transfer function" button, the instrument behaves as a dual channel FFT analyzer referencing one channel to the other and calculating the resulting transfer function. This is especially useful for calculating transfer functions from music signals. The multimeter can be slaved to the FFT analyzer making it possible, for example, to monitor or set an overall measurement level, such as when testing a loudspeaker.

Sinusoidal Analysis: Inside the sinusoidal control panel you can measure frequency response, impedance, and harmonic distortion. The sine wave stimulus for these measurements can be stepped or swept through user-defined frequency limits. In the stepped mode, steps of 1/3 to 1/48 octave are available. The stepped signal can be gated to remove time-of-flight, allowing quasi-anechoic frequency response measurement of loudspeakers. Second through fifth harmonic distortion can be plotted along with the frequency response of the DUT.

Possible measurement quantities include voltage units in dBV, dBu, and dBRel, pressure in dBSPL, and impedance in ohms. Impedance can be measured using the signal generator's internal impedance in a voltage divider mode or in a constant voltage mode using one of Audiomatica's QC amplifier/switchbox models. All data can be smoothed in 1/12 through ½ octave bands. Available post-processing options are the same as those in the MLS & Chirp control panel.

Linearity and Distortion Analysis: In this control panel you can measure the input/output linearity and distortion of electronic amplifiers. In the linearity mode output is plotted against input at a given frequency. Minimum and maximum input levels are specified along with the number of steps to be included in the analysis. Ideally the resulting curve should be a straight line equal to the DUT gain, but in practice amplifier saturation will show up as a flattening of the gain curve.

THD can also be measured as a function of input level at a specified frequency. Here distortion components up to the fifth are computed via FFT so that they are true THD minus any noise. Intermodulation distortion computation using SMPTE, DIN, or CCIF criteria is also mechanized.

L_{eq} Analysis: The Leq Analysis control panel provides real-time capture and level measurement of any signal present at CLIO's input. In this mode CLIO acts like a graphical level recorder with optional direct-to-disk data capture. When analyzing an acoustical event this control panel gives you complete information about the equivalent continuous sound level (Leq) and related quantities according to IEC 61672 standard. When used together with FFT frequency analysis you get a complete integrating sound level meter.

In the display up to five quantities can be displayed versus time: L_{eq}, L_{slow}, L_{fast}, L_{User}, and peak value. L_{slow} and L_{fast} refer to levels measured with slow and fast integration times. L_{User} is a user-specified maximum level. Time resolution, frequency weighting, peak mode (maximum or user specified), and integration time are user selectable in the L_{eq} settings dialog box. If the "Capture time to disk" option is selected, the real-time data is saved to the hard disk and can be converted into a standard wave file for later post-processing.

Wow and Flutter Analysis: In this panel wow and flutter are measured according to both IEC and NAB standards. The entire process is carried out in the digital domain and is therefore much more accurate than traditional analog methods. Both time and frequency domain analyses of the demodulated signal are available to analyze rotational stability of turntables or the speed accuracy of a tape deck. In addition to the time history of the demodulated signal, linear and weighted percentage wow and flutter values according to both IEC and NAB standards are presented along with the average frequency produced at the DUT output.

Post-Processing Control Panels

Waterfall and Directivity Analysis: This control panel adds a third dimension to measured data obtained in one of the previously discussed control panels. Waterfall and color plots include cumulative spectral decay (CSD) and energy-time-frequency (EFT) analysis of a measured impulse response. These plots are shown in the time-frequency plane. In plotting the CSD you can specify the start and stop frequencies, the number of spectra, the time shift between spectra, and the window rise time. The plots can be referenced to the initial spectra making the decay frequencies more apparent, and you can apply 1/12 to ½ octave smoothing to the spectra.

Directivity analysis derives its data from a sequence of frequency responses taken at fixed angular intervals. The data can be plotted in the frequency-angle plain, in which case it appears as a waterfall plot. Alternately, CLIO can display the information in a color plot or conventional polar plot.

CLIO can control Outline and Linear X turntables through its "Turntable Controls" and "Autosave" dialog boxes, greatly simplifying the process of obtaining response data at multiple angles. In the case of the Outline turntables, control of both the single-axis and two-axis models is possible. In the Autosave dialog box you can specify the starting angle, angular increment, and the total number of measurements. Then activating the "Autosave" and "loop" radio buttons and pressing "go," CLIO will take the specified number of responses, pausing between measurements to send a control signal to the turntable, and waiting a sufficient time to allow it to reach its new position before taking the next measurement.

Thiele/Small Parameter Analysis: CLIO uses impedance data taken in either the MLS or sinusoidal control panels to estimate Thiele/Small (T/S) parameters of loudspeaker drivers. From a dropdown menu the operator can select either sinusoidal or MLS impedance data currently in memory or an impedance file from an earlier measurement for the analysis. The only additional data needed are the driver voice coil DC resistance and in the case of woofers, the cone diameter.

As is well known, two impedance measurements are needed to get the full set of T/S parameters. The first is the driver's free-air impedance. The second consists of one impedance curve taken with a known mass added to the cone (the delta mass method) or with the driver mounted in a sealed enclosure of known volume (the delta compliance method). Both methods are available in CLIO.

Two options are available to estimate the T/S parameters. The first method uses the standard three-point impedance data plus a frequency shift to quickly compute T/S values. The second approach least-squares fits a driver electric circuit model to the impedance data using the first result as a starting point. The second method takes some additional computing time, but is generally more accurate. The result is a set of 27 electrical, acoustic, and mechanical parameters describing the tested driver. The drive level is user specified so T/S parameters can be measured over a wide range of drive levels.

Acoustical Parameter Analysis: In this control panel a measured room impulse response is post-processed to calculate the acoustical parameters as defined by the ISO 3382 standard. These quantities describe the behavior of auditoria and concert halls and are applicable to any room intended for speech or music reproduction.

There are three main modes in this panel. The Impulse Display mode displays the Schroeder reverberant decay of a selected octave filtered room impulse response. One-third and octave filtering options are available. The ETC mode shows the energy time plot for a similarly filtered impulse response. The frequency display mode plots the value of a selected parameter versus frequency. The computed acoustical parameters include: sound level, early-late arrival balance, and decay time measurements. The range of display options for these parameters is extensive, making visualization of the room acoustics easy to grasp.

Wavelet Analysis: In the Wavelet Analysis tool the user can post-process a measured impulse response with a wavelet transform to produce a color plot of signal energy versus time and frequency. Unlike the FFT, the wavelet transform does not have a fixed time-frequency resolution. Rather it has a fixed time resolution-frequency resolution product. The Wavelet Analysis algorithm mechanized in CLIO uses a kernel of the modified complex Morlet Wavelets.

Individual wavelets can be thought of as behaving somewhat like bandpass filters. The transform computes the mathematical projection of each wavelet on the impulse response. These projections or coefficients are then a representation of the impulse response in the time-frequency domain. Varying the Q of the wavelets, you can trade frequency resolution for time resolution. Qs ranging in values from 3 upwards can be selected for the analysis.

The magnitude squared of the wavelet coefficients is directly proportional to the energy in the impulse response in a region around a point in the time-frequency domain. CLIO depicts the magnitude squared wavelet coefficients in a color plot called a Scalogram. Each coefficient is plotted as a point on the Scalogram at its associated time-frequency position. If every frequency slice in the Scalogram is normalized to the peak value in that slice, the resulting plot can be viewed as the time-frequency energy decay of the loudspeaker. This plot will normally display a ridge of peak energy along the frequency axis.

Ideally, the projection of this ridge onto the time frequency plane should be a straight vertical line indicating that all energy peaks arrive at the measurement point at the same time. Departures from a straight line indicate time dispersion in the impulse response. An example later in this article will make some of the discussion of this new analysis technique more clear.

Data and Graphics Export Options

CLIO supports a wide range of data and graphics export options. They are explained here briefly.

CLIO exports the currently active measurement in ASCII format. In the MLS & Log Chirp control panel frequency data (amplitude and phase), the complex FFT data at the active resolution and impulse response time data can be selected for export. In the FFT & RTA control panel frequency data and FFT data are available for export. In the case of multiple measurements the last captured set of FFT and/or time data can be exported. Sinusoidal frequency response and harmonic distortion data are export options on the Sinusoidal control panel.

For graphics export CLIO can produce enhanced metafiles (*.emf), bitmaps (*.bmp), portable network graphics (*.png), jpeg (*.jpg), or gif (*.gif) figures of the currently active screen. The graphs can be generated in the current screen colors or in black and white at the operator's choice. Alternatively, a user-defined printing option is available that can be previewed on the active screen before export. Up to 9 overlays can be plotted along with the current active measurement, greatly facilitating measurement comparisons.

Graphics export options will be illustrated in the later examples. I will present many screen shots to give you the look and feel of CLIO.

Examples

The following examples concentrate on the evaluation of a highly regarded two-way monitor loudspeaker using many of CLIO's analysis tools. The instrument test setup for these examples is shown in ***Photo 1.*** In addition to the FW-01 Audio Interface on the left, a Model 4 QC amplifier-switch box is shown in the middle of the photo. This unit is central to the implementation of CLIO's excellent QC functions. In the examples here, however, only its 50W amplifier was used. Microphones employed in these tests included the Earthworks MD30 and an ACO Pacific microphone comprising a 7016 ¼″ microphone capsule with the AD7016 adaptor and 4012 ½″ preamp. Polar response data was taken with an Outline ST1/ET1 turntable and electronic controller combination under CLIO control.

Frequency Response

Figure 1 shows a screen capture of the measured impulse response for the example loudspeaker. I measured this impulse response with an MLS stimulus of 16K length. The tweeter height is 1m above the floor and the microphone is placed 1m from the tweeter. The floor bounce can be seen just beyond 6.9ms. The impulse has been windowed between 2.6ms and 6.9ms to eliminate the floor bounce and much of the speaker to microphone fly time. The legend below the plot indicates a total windowed time interval of 4.25ms and a corresponding frequency resolution of 235.29Hz. From the tool bar above the plot you can compute and display the frequency response, the step response, the Schroeder decay, or the energy-time curve.

Pressing the frequency response button yields ***Fig. 2,*** another screen capture. The displayed frequency response has been 1/12 octave smoothed. Using the magnifier function the plot scale has been expanded to cover the frequency range from 100Hz to 20kHz to better display the valid portion of the measured frequency response. From 500Hz up the response fits within a 2.7dB window.

Pressing the Φ operator button on the tool bar, CLIO computes and displays phase response. The resulting wrapped phase is plotted in red in ***Fig. 3.*** Unwrapped, the phase amounts to 2700° at 20kHz. This is due to the setting of the impulse response start cursor at 2.6ms which includes some of the speaker to microphone fly time. CLIO can correct this problem.

Right-clicking the group delay button to select the excess group delay computation, you get ***Fig. 4.*** Excess group delay

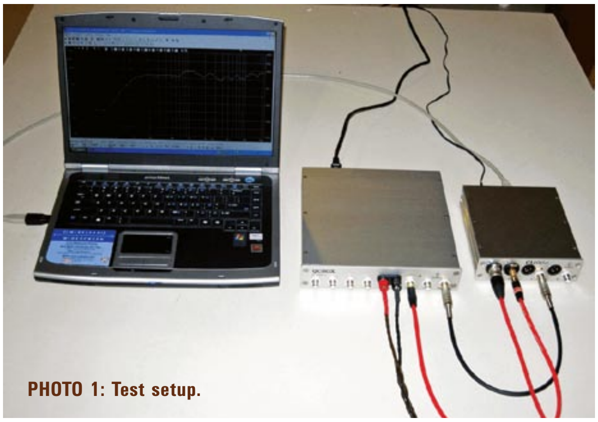


PHOTO 1: Test setup.

is the derivative of excess phase. In regions where the excess group delay is constant, all excess phase response is linear in frequency and thus represents a pure time delay. This is the additional speaker to microphone delay beyond the setting of the start cursor in ***Fig. 1.*** Referring to ***Fig. 4,*** notice that the curve is flat (i.e., constant) between 10 and 20kHz at a value of 0.58ms. This represents the additional fly time for the tweeter beyond the position of the start cursor.

Returning to ***Fig. 3*** you can invoke the MLS post-processing dialog to remove the additional time delay from the phase calculation to produce the phase response shown in green. Because the tweeter response is minimum phase in the 10 to 20kHz region, the green curve represents the loudspeaker phase response referenced to the location of the tweeter's acoustic phase center.

Time-Frequency Behavior

Using two of CLIO's post-processing control panels, Waterfall and Wavelet, you can examine the time-frequency behavior of the example loudspeaker. Look at the cumulative spectral decay (CSD) first.

CSD Analysis: The CSD measures the frequency content of a loudspeaker's decay response following an impulsive input. It is represented by a 3-dimensional time-frequency plot. On the CSD plot, frequency increases from left to right and time moves forward from the rear. The first slice analyzes the impulse response out to a fixed end point which you can select by appropriate placement of a cursor. It is usually selected as that point in time just before the arrival of the first reflection so that the first slice is the quasi-anechoic frequency response in ***Fig. 2.*** Succeeding slices are foreshortened toward this end point, including less and less of the impulse response tail with each succeeding slice. The FFT of these slices yields the frequency content of later and later portions of the impulse response.

The CSD is most useful in identifying resonances, which appear as ridges moving forward along the time axis. When representing a CSD the program automatically hides the low-frequency part of the spectra that has become unreliable due to the decreasing portion of the impulse response used in the calculation.

The CSD for the example loudspeaker is shown in ***Fig. 5.*** Frequency ranges from 300Hz to 20kHz and time goes from 0.00ms to 5.92ms. The spectra have been 1/6 octave smoothed. The first 2ms show the general decay of the full system response. Beyond 2ms, however, you see the emergence of resonances. There is a broad ridge of delayed energy between 1 and 2kHz. Also, there are narrower, but pronounced, ridges at 3, 4, 5, and 6kHz. These ridges break out from the general decay some 15 to 17dB below the initial response. The audibility of these delayed reso-

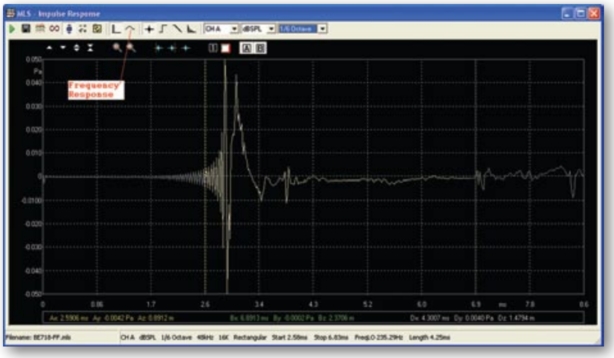


FIGURE 1: Impulse response for example loudspeaker.

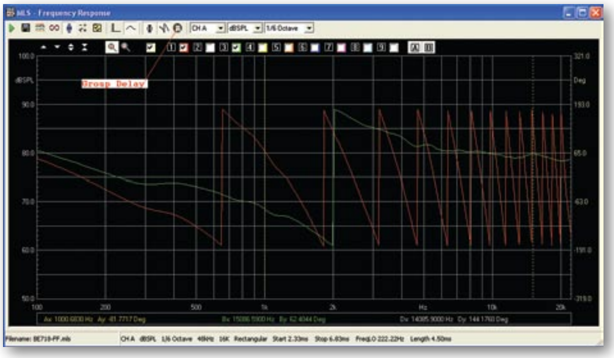


FIGURE 3: Initial phase response (red) and corrected phase (green).

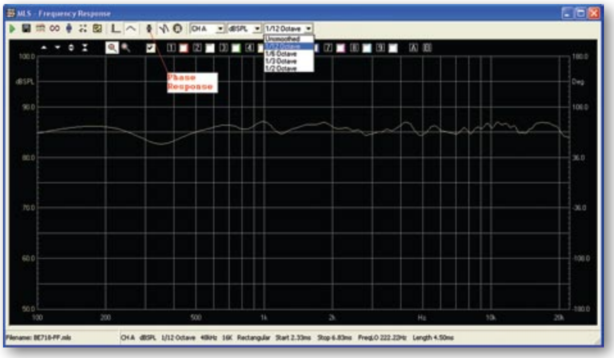


FIGURE 2: Far-field frequency response for example loudspeaker.

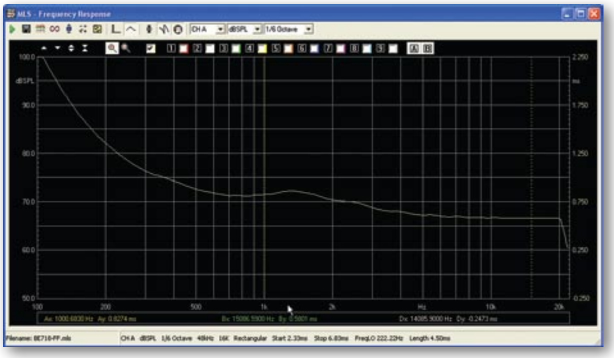
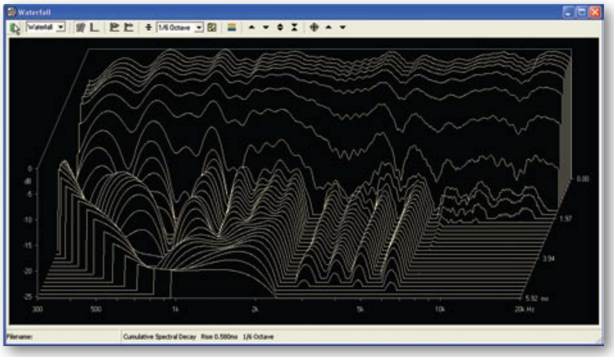
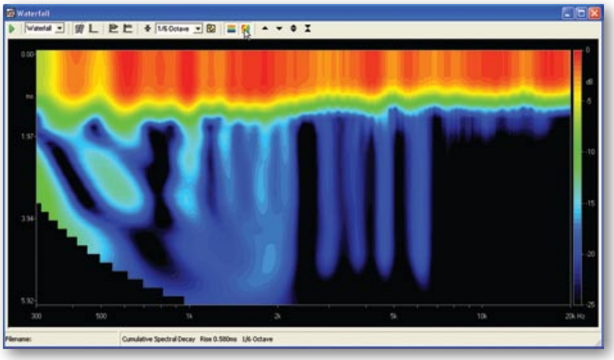


FIGURE 4: Excess group delay.



Cumulative Spectral Decay Rise 0.580ms 1/6 Octave

FIGURE 5: Cumulative spectral decay for example loudspeaker.



Cumulative Spectral Decay Rise 0.580ms 1/6 Octave

FIGURE 6: Color plot of cumulative spectral decay.

nances is not discussed here.

CLIO has the added feature of showing the CSD in a color plot (***Fig. 6***), where all later spectra are referenced to the initial response to better highlight the decay behavior. Again, you see the broad ridge of delayed energy between 1 and 2kHz plus the finger-like ridges at 3, 4, 5, and 6kHz. Relative to the waterfall plot, the color map better represents the frequency of decaying modes because they plot as straight color patterns parallel to the time axis.

Wavelet Analysis: In the CSD analysis time is precisely known. Frequency resolution, however, is limited by the time span of the truncated impulse response. Wavelet analysis provides you with an alternate view of the time-frequency behavior of the example loudspeaker. The normalized wavelet spectrogram in ***Fig. 7*** is an example of exported color plot.

Referring to ***Fig. 7,*** each horizontal slice of this color plot shows the energy distribution of the impulse response over time at the frequency associated with that slice. For this plot the wavelet Q was set at 3. The plot is normalized at each frequency to the maximum energy at that frequency. As such, it gives an indication of the loudspeaker's time dispersion.

At low frequencies energy is spread out over a time span of about 8ms. At 20kHz the span is less than 0.24ms. The wavelet analysis covers a larger time span than the CSD due in part to the temporal uncertainty in the transform. At 15kHz the time of maximum energy occurs at approximately 2.9ms. At 1000Hz the value is 3.15ms. Thus in an energy sense the woofer is about 0.25ms behind the tweeter.

Returning back to the excess group delay plot of ***Fig. 4,*** notice that I have placed cursors at 1000Hz and 15kHz. Referring to the legend below the plot you see that the time difference between the two points is 0.2473ms, which agrees quite well with the wavelet analysis.

Full Range Response: So far discussion of the results for the example loudspeaker has been limited to 250Hz and above. The low-end response can be obtained using Keele's near-field technique[1]. Details of the procedure are given in Chapter 4 of reference 2. CLIO's post-processing math functions are essential to the process. First, near-field woofer and port measurements are taken. Then the port response is scaled by the port to woofer diameter ratio using the "multiply by a value" post-processing option.

Next the woofer and scaled port near-field responses are added with the file adding function to get the low-frequency response. Finally, the low-frequency and high-frequency responses are merged at 250Hz using the post-processing merge function to get the full-range response of the example loudspeaker. The process is summarized in ***Fig. 8,*** where the MLS Processing Tools dialog box is shown in the "merge" option. Here the merge frequency is set and the low-frequency file to be merged to the active high-frequency response is selected.

Polar Response

As previously explained, CLIO automates the entire process of taking response measurements at multiple angles to evaluate a loudspeaker's polar response. The example

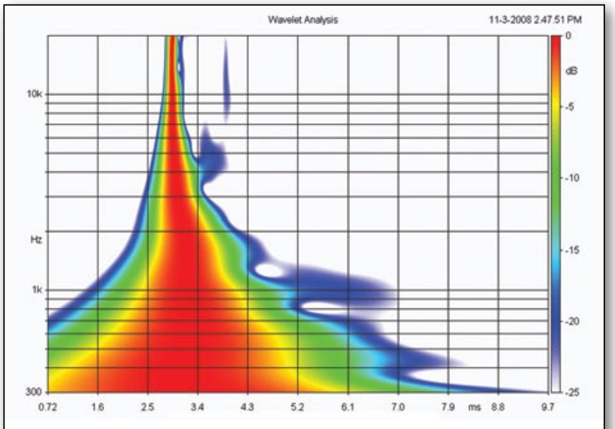
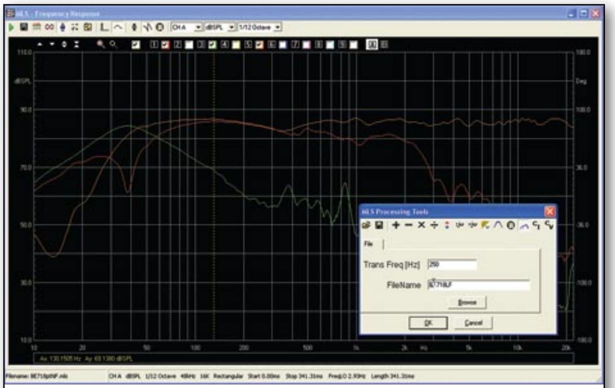


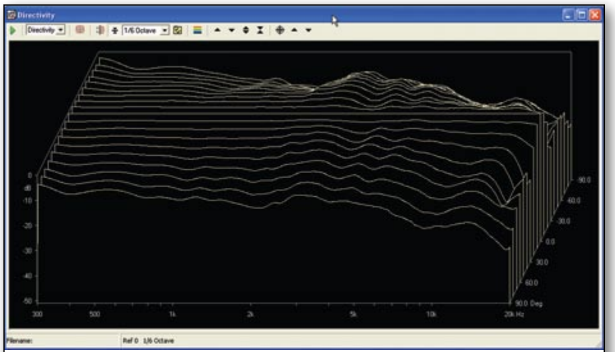
FIGURE 7: Wavelet analysis: time-frequency energy normalized (Q = 3, BW = 0.333 octaves).



Trans Freq [Hz] 250

FIGURE 8: Illustrating method for obtaining full range response; woofer (red), port (green), full-range response (orange).

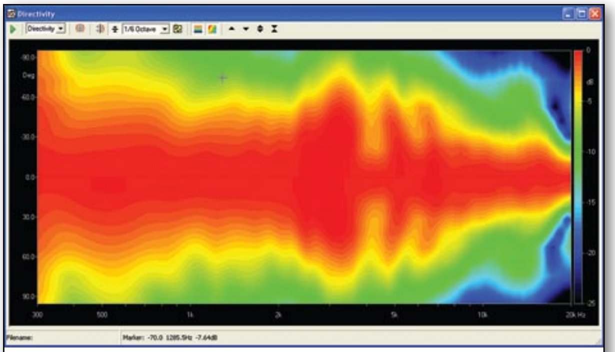
loudspeaker response was measured in 10° increments from –90° to +90° in the horizontal plane. Using the directivity option in the Waterfall & Directivity control panel, you can plot the resulting measurements as shown in ***Fig. 9.*** Here all off-axis plots have been referenced to the on-axis response so that the plot actually shows the *change* in response as you move off-axis.



Filename: Ref 0 1/6 Octave

FIGURE 9: Normalized horizontal polar response for example loudspeaker.

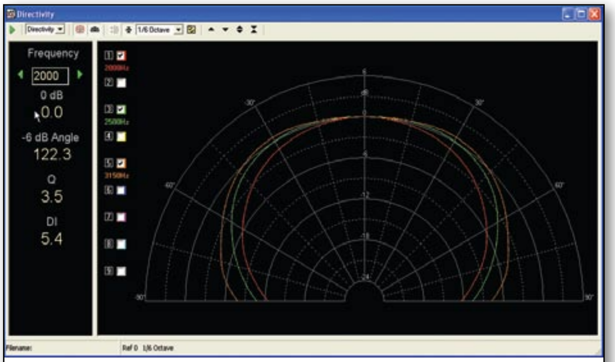
Examining ***Fig. 9,*** there appears to be a slight flare in the off-axis response around 3kHz. That is, the response rises above the on-axis response at off-axis angles. This is more easily seen in the color plot of ***Fig. 10.*** Here you see a narrowing of the woofer response up to the crossover frequency of 2kHz. Beyond 2kHz the broader polar coverage of the tweeter causes the flare in polar response.



Filename: Marker: -70.0 1285.5Hz -7.64dB

FIGURE 10: Color plot of normalized horizontal polar response.

CLIO gives a third view of polar response in the classical angular polar plots. ***Figure 11*** plots polar response at 2000, 2500, and 3150Hz. Again, you can see the widening polar coverage with increasing frequency.



Frequency
2000
0 dB
0.0
-6 dB Angle
122.3
Q
3.5
DI
5.4

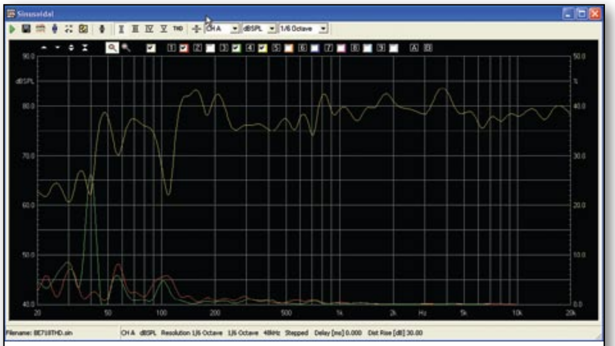
Filename: Ref 0 1/6 Octave

FIGURE 11: Traditional plot of horizontal polar response.

Sinusoidal Analysis

The sinusoidal frequency response for the example loudspeaker is shown in ***Fig. 12.*** This response (yellow) was made in 1/12 octave steps from 20Hz to 20kHz. Also plotted are second (red) and third (green) harmonic distortion levels. Distortion levels can be read off the left side vertical scale. Gating was not activated so this response includes room reflections. Ideally, distortion should be measured in an anechoic chamber. Not having one, I placed the microphone on the tweeter axis at a distance of 0.5m to—I hope—minimize room effects.

Above 200Hz distortion is admirably low. The large response dip just above 100Hz is caused by a panel resonance in the ceiling just above the loudspeaker. The rise in distortion at that frequency is due to the panel and not the loudspeaker. The large third harmonic level at 40Hz is due to excessive woofer excursion below the port tuning frequency.



Filename: BE718THD.sin CH A dBSPL Resolution 1/6 Octave 1/6 Octave 48kHz Stepped Delay [ms] 0.000 Dist Rise [dB] 30.00

FIGURE 12: Sinusoidal frequency response (yellow), second harmonic distortion (red), third (green).

FFT & RTA Analysis

I start this discussion by examining CLIO's dynamic measurement range. To do this a self-noise test was conducted using an FFT analysis. This was accomplished by shorting input to output on Channel A and starting the FFT analysis with no stimulus. The sample rate was increased to 96kHz giving an analysis bandwidth of almost 48kHz.

Fifty measurements were taken and linearly averaged, an option CLIO provides. The average was then 1/24 octave smoothed to get the result shown in ***Fig. 13,*** which is another example of graphics export. Above 100Hz the self-

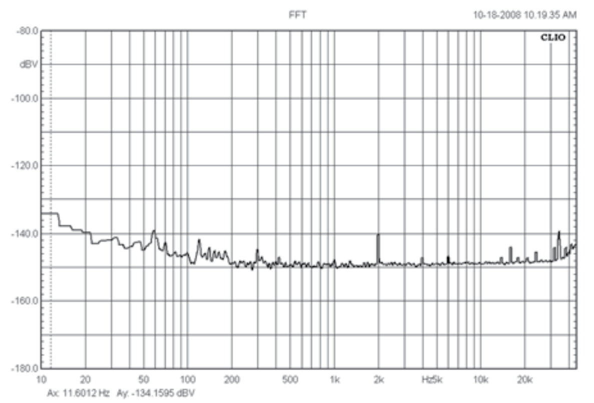


FIGURE 13: Spectrum from CLIO 8 self-noise test.

noise level is averaging almost -150dBV. Even at 10Hz you have a level of -134dBV. Given a maximum input level of +40dBV, you see that CLIO has an overall dynamic range of 190dBV.

RTA analysis: Next I ran an RTA analysis of the example loudspeaker using CLIO in the RTA mode. This mode is invoked in the FFT & RTA analysis control panel by highlighting the RTA-Octave band radio button. I used pink noise of length 32768 to make the measurement at a 48kHz sample rate. I set the "Time data-Oscilloscope" mode in the FFT panel and opened the multimeter control panel and set it to read SPL. I then minimized this panel and slaved it to the RTA analysis. This allows a real-time reading of the SPL during the measurement.

I adjusted SPL to approximately 78dB at 1m. ***Figure 14*** shows the result. Here you see the RTA response which is the result of 50 measurements averaged linearly. You also see a sample time trace from the last of the 50 measurements.

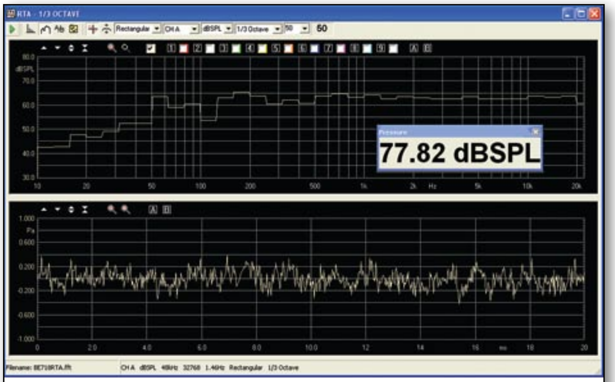


FIGURE 14: RTA response for example loudspeaker.

Distortion analysis: FFT analysis is very useful in providing a detailed look at distortion products. As an example of this property, a two-tone intermodulation distortion (IMD) test was run on the tweeter of the example loudspeaker. Equal amplitude sine waves of 10 and 11kHz were input, with the loudspeaker using the Model 4 amplifier. The sample rate was set to 96kHz. The result of this test is shown in ***Fig. 15.***

First notice the multimeter reading of 89.99dB SPL. Next you see essentially equal amplitude tones at 10 and 11kHz. There are also harmonics of the tones at 20 and 22kHz at levels of 28 and 32dB SPL, respectively. These levels correspond to 0.08% and 0.12% harmonic distortion, respectively. The second-order IMD product at 21kHz is at a level of 36.8dB, or 0.22%.

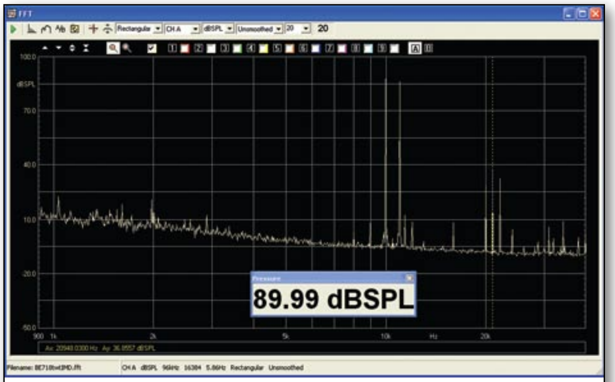


FIGURE 15: Tweeter two-tone IMD test spectrum.

Closing Remarks

Of course, no review is complete without mentioning a few additional features I would like to see. The process of getting a full-range speaker response from near-field measurements requires invoking a sequence of three separate post-processing functions. It would help to have a single dialog box in which to add near-field port and woofer responses.

The post-processing merge operation does not allow the merging of response data with different resolutions. When measuring the near-field low-frequency response of vented boxes, it is often desirable to use a much finer resolution (longer sample length) than that needed for the far-field response. An additional post-processing function that would interpolate the far-field response to the resolution of the near-field response would be helpful.

CLIO has two cursors which allow you to read the value of the active data curve at two locations. CLIO also gives the difference between the two points. It would be useful to have the ability to read the difference between the active curve and a curve taken previously. Currently this is not possible.

Finally, with regard to the wavelet analysis, determining the point of maximum energy at each frequency is difficult because the color plot does not provide sufficient visual resolution. It would be helpful to plot the ridge of maximum energy as a curve on the scalogram.

I hope my emphasis on loudspeaker evaluation has not led you to miss the full scope of CLIO's measurement and analysis capabilities. I have been a CLIO user for over a decade, starting back with the early DOS version. This version of CLIO is by far the most complete, accurate, intuitive, and user friendly version to date. Navigation through CLIO's many functions is very easy using either a mouse or the many control key options. Its easy portability is a strong recommendation.

The manual for CLIO 8 is one of the best I have seen for a measurement suite. All functions are fully explained with many excellent examples and details showing how to make measurements with minimum error. CLIO has a fully developed QC option aimed both at engineering development and production control. Unfortunately, there is neither time nor space here to cover that option. It is described in full detail in the excellent QC manual. ***VC***

REFERENCES

1. D.B. Keele, Jr., "Low-Frequency Loudspeaker Assessment by Nearfield Sound Pressure Measurement," *JAES*, Vol. 22, pp. 154-162 (April 1974).

2. D'Appolito, J.A., *Testing Loudspeakers*, Audio Amateur Press, 1998.

Manufacturer's Response:

I am delighted to read, once again, a complete and detailed technical review from Joe D'Appolito. Here at

Audiomatica we are particularly proud and honored that he touched our latest design effort, CLIO in its FW version. The year 2009 marks our 25th year of activity and the 18th birthday of CLIO.

His critiques and suggestions—totally sharable—are on the desk of our software guys. Some were already on our wish list, some are under implementation in the new CLIO 10 system software that should be released by the date of publication of the review. Let me say that, among many other new features, CLIO 10 is capable of automating two-turntables data collection for executing 3-D directivity measurements; results are presented as 3-D graphs also known as "balloons" and may be exported to common formats for integration in external simulation software packages.

Focused on loudspeakers, this review is so comprehensive that it seems to me a natural addendum to the book *Testing Loudspeakers*. Thank you again, Joe!

Mauro Bigi
Audiomatica
Vice President

Joseph D'Appolito, regular contributor and author of many papers on loudspeaker system design, holds four degrees in electrical and systems engineering, including a Ph.D. Previously, he developed acoustic propagation models and advanced sonar signal processing techniques at an analytical services company. He now runs his own consulting firm specializing in audio, acoustics, and loudspeaker system design. A long-time audio enthusiast, he currently serves as chief engineer for Snell Acoustics.