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MEASURING TRANSIENT EVENTS BECOMES LESS CHALLENGING WITH THE RIGHT APPROACH AND TOOLS.

Quantitative analysis yields objective audio-amplifier click and pop measurements

Product differentiation in portable audio devices is a hot topic. But what makes one product better and more desirable than its similarly specified rival? From a performance viewpoint, the usual audio figures of merit, such as frequency-response flatness, THD+N (total harmonic distortion plus noise), and clipping levels may be too similar to point to a winner.

The user interface is an obvious differentiator, but more subjective audio-performance parameters can set one product above another. One such factor is the occurrence of "clicks" and "pops" or other strange, transient noises audible through the headphones or speakers when a user turns the unit on or off. Although these types of events are difficult to assess, a method that quantifies this click and pop parameter allows meaningful, repeatable comparisons between components.

The term "click and pop" refers to the unwanted, audio-band transient signals that a headphone or speaker reproduces when something enables or disables the amplifier driving the transducer. In portable-audio applications, in which saving power is key to extending battery life, the internal controller often disables functional blocks when they are not required. An ideal component would exhibit no audible output when the controller enables or disables the device, but, in practice, all audio amplifiers exhibit click and pop to some degree. The effect of this phenomenon varies, depending on the sensitivity of

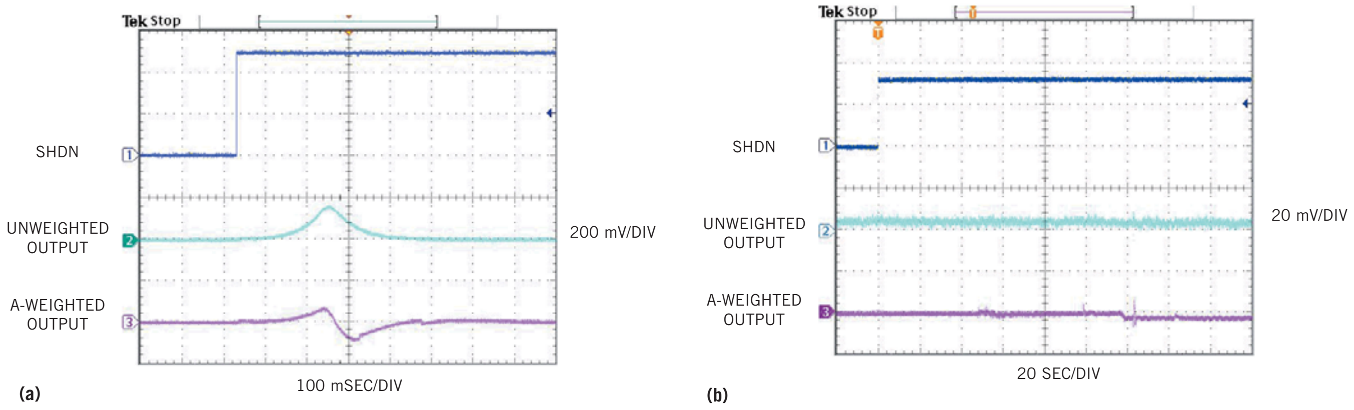


Figure 1 The transient event associated with a particularly well-behaved, ac-coupled headphone amplifier brought out of shutdown, although high in amplitude, produces a predominantly low-frequency sound, to which the ear is less sensitive (a). The amplitude of the transient event associated with a low-offset, dc-coupled headphone amplifier brought out of shutdown is much lower and hence, subjectively quieter, and the amplifier is fully enabled after 150 μsec (b).

TABLE 1—TRANSIENT NOISE EVENTS IN AMPLIFIERS

1	Powered up (power applied)	Category A
2	Powered down (power removed)	Category A
3	Brought out of shutdown (power applied previously)	Category B
4	Forced into shutdown (power still applied)	Category B

the transducer—speaker or headphone—in the product, its distance from the user's ear, the amplifier's ability to handle this transition, and the user's hearing. Many factors contribute to determining a threshold of audibility, but engineers can characterize the amplifier output to enable quantifiable product comparisons, independent of any acoustic transfer function. **Table 1** lists four key events that are most likely to cause transient signals in an amplifier.

Until recently, the industry's characterization of this undesirable effect has been almost purely subjective. Marketing phrases, such as "low pop noise" and "clickless/popless operation," illustrate the subjectivity companies apply when quantifying click and pop performance. Customer expectations are changing, however. As time and familiarity bring about higher performance expectations, transient-free audio performance is becoming an important selling point for portable audio devices. One consequence is the growing need for an objective figure of merit in describing the click and pop phenomenon.

CALIBRATING EQUIVALENT EQUIPMENT

TABLE A—AUDIO PRECISION SYSTEM TWO CALIBRATION RESULTS

V_{IN} (mV p-p)	$V_{THEORETICAL}$ (dBV)	$V_{READING}$ (dBV)	A-weighting calibration
1	−60.000	−66.295	6.295
5	−46.021	−52.391	6.370
10	−40.000	−46.186	6.186
20	−33.979	−39.883	5.904
40	−27.958	−34.120	6.162
60	−24.437	−32.140	7.703
80	−21.938	−30.791	8.853
100	−20.000	−28.747	8.747

Deriving an objective figure of merit for click- and pop-performance can allow you to compare the performance of devices claiming click- and pop-suppression capability. However, what can an engineer accomplish if a System One or Two audio analyzer from Audio Precision, or a similar unit, is unavailable?

It's possible to use equivalent test equipment from other manufacturers to implement click- and pop-performance measurements. **Figure A** shows a generic test setup for an audio analyzer plus device under test.

Calibrate this test setup before recording accurate measurements and making direct comparisons of results. In addition, verify that the amount of energy recorded by the equivalent analyzer is actually linear with the varying input amplitude. Only then can you be sure that the instrumentation accurately represents click and pop energy, especially when it is reacting to fast-rising transients with significant energy above the audio band.

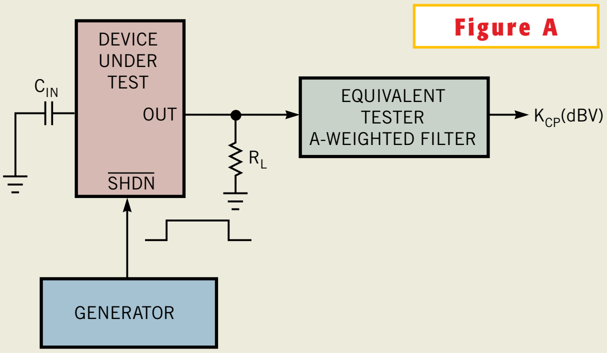
Simple calibration requires a function generator and an equivalent analyzer (**Figure B**). Calibrate using the following steps:

1. Apply a known-amplitude, 0.5-Hz square-wave signal directly to the input of an equivalent audio analyzer.
2. Set the equivalent audio analyzer to detect A-weighted, peak voltages.
3. Record the peak voltage reading of various input signal amplitudes.

Table A outlines the calibration results of a System Two Audio Precision audio analyzer set to detect A-weighted peak voltages at 32 samples/sec. An auto-range setting of 1X/Y yields a consistent 6-dB weighting factor for input signals of 1 to 40 mV p-p. This 6-dB weighting factor is due to the limited, A-weighted transfer function of the Audio Precision analyzer. At input-signal levels greater than 40 mV p-p, the calibration results become nonlinear for this setup. However, this range is adequate for most amplifiers.

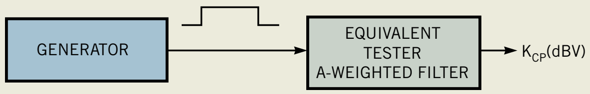
You can apply this calibration exercise to equivalent analyzers to ensure accurate click- and pop-performance measurements. Additionally, once you identify calibration values and determine an appropriate input-signal range, you can accurately compare the click and pop performance of two amplifiers you have characterized with equivalent audio analyzers.

Figure A



Equivalent test setup for click and pop measurements allows the acquisition of click- and pop-performance measurements by using test equipment from other manufacturers.

Figure B



Calibrating the test setup for equivalent audio analyzers ensures that the amount of energy recorded by the equivalent analyzer is actually linear with varying input amplitude.

A time-domain analysis shows the transient events that occur with bringing two headphone amplifiers out of shutdown mode. Compare the transient amplitude of an ac-coupled headphone amplifier (**Figure 1a**) to that of a dc-coupled headphone amplifier (**Figure 1b**). The first device produces a large transient and a predominantly low-frequency sound, resulting from its relatively slow turn-on sequence. (Note the time scale is 100 msec/div.)

The transient of the second headphone amplifier appears to be lost in the noise floor of the oscilloscope, before A-weighted filtering. For this type of amplifier, most of the audible event derives from the shift in the dc voltage offset from shutdown to full operation. Because the offset is just a few millivolts, an unfiltered scope trace does not accurately determine the magnitude of the click or pop. Applying A-weighted filtering extracts from the noise floor the click and pop caused by the offset of the dc-coupled headphone amplifier and allows the transients to be observed. (Note that the vertical axis of the post-filtered signal is not recorded to scale.) Analyzing this problem raises two main questions: How can designers objectively measure the transient? And, what, if any, pass/fail criteria can they apply to the measured results?

CLICK- AND POP-MEASUREMENT METHOD

Maxim's audio group has developed a universal method for measuring click and pop performance (**Figure 2**). This technique employs a System One or System Two (preferred) audio analyzer from Audio Precision (www.audioprecision.com), but engineers can also implement the test method with equivalent test equipment from other manufacturers, such as Rhode & Schwartz's Audio Analyzer and Prism Sound's dScope. The group's proposed figure of merit, K_{CP}, provides an objective representation of audio amplifier click and pop performance.

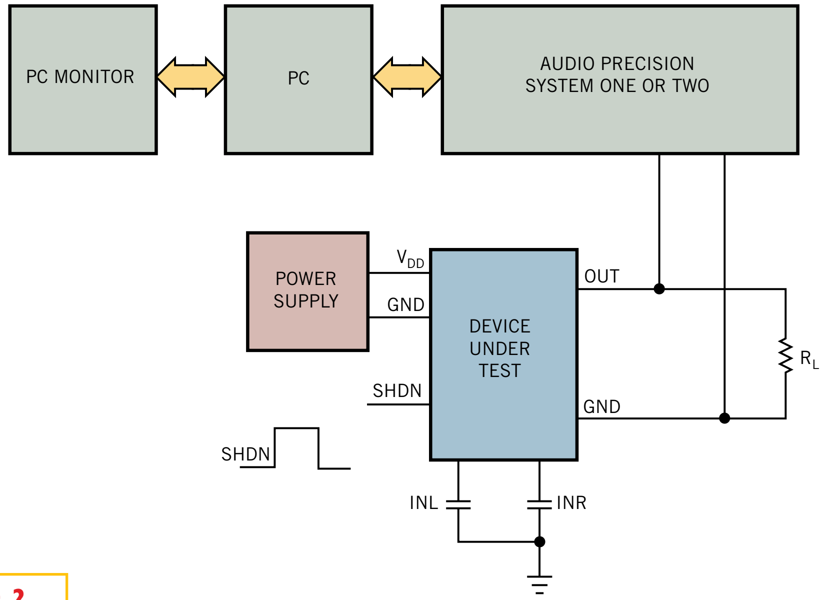


Figure 2

The test setup for click and pop measurements in headphone amplifiers includes left and right input pins ac-coupled to ground, outputs loaded with typical headphone impedance, and the shutdown pin toggled by a square-wave generator.

First, connect the output of the DUT (device under test) to the expected load impedance or a simulated, dummy version of that impedance. Make the required shutdown (SHDN) and power signals available to the DUT and provide an ac ground connection for all DUT inputs. No input signal is necessary; the input stimulus consists of moving the DUT between its various modes of operation and nonoperation. Connect the DUT output to the analog-analyzer section of the audio test equipment.

Next, select the analyzer's A-weighted filtering option (preferred) or the unweighted 22-Hz to 22-kHz filters to limit the measurement bandwidth. Note that an oscilloscope display of a fast, high-level transient does not indicate how much energy will appear in the audio band. The human ear has a limited frequency response, as does the loudspeaker or headphone that tries to follow the transient. Thus, the addition of A-weighted filtering is arguably more useful, because it emphasizes frequencies to which the ear is more sensitive (**Figure 3**). Some audio analyzers cannot apply A-weighting; in such cases, it is important to limit the bandwidth to frequencies to which the human ear responds. A common bandwidth range for audio tests is 22 Hz to 22 kHz, presumably to allow bandwidth-limiting filters to have a flat response up to 20 kHz, which is usually cited as the upper limit for the human ear.

Set the detector to peak reading, rather than the usual rms setting, and set the detector sampling to 32 samples/sec. It is meaningless to use rms detection for a transient event such as the kind that this method tries to capture. System Two analyzers allow higher sampling rates, but using the 32-sample/sec rate, which is the fastest acquisition setting on a System One audio analyzer, allows you to obtain

TABLE 2–K_{CP} VALUES FOR HEADPHONE AMPLIFIERS (A-WEIGHTED, 32-SEC, PEAK VOLTAGES, 32Ω LOAD)

Part no.	K_{CP}		Comments
	Into shutdown (dBV)	Out of shutdown (dBV)	
MAX9750C HP amplifier	−55.8	−47.9	3-dB gain setting
MAX9760 HP amplifier	−57.4	−56.2	Unity gain, 15Ω resistors, 220-μF output capacitors
MAX4410	−69.9	−77.8	Unity gain, 10-kΩ resistors
MAX4299	-59.1	−49.4	Category A (no shutdown)

equivalent measurements from both devices.

Disable the autoranging circuitry of the audio analyzer and manually select a range that will accurately track the expected peak signal amplitude. System One and System Two analyzer ranges are in 4× (12.04-dB) steps from 1× to 1024× (0 to 60.21 dB). A 1x/y range for audio amplifier click and pop measurements is a good starting point for highest accuracy measurements.

Drive the shutdown pin with a low-frequency square wave to allow the acquisition of multiple measurements. Cycle the shutdown pin at a frequency below the audio bandwidth, with a period long enough to ensure the capture of all turn-on/turn-off audio events; some parts exhibit long turn-on delays. At Maxim, this rate is usually 0.5 Hz.

The analyzer's bar-graph option lets you easily monitor the DUT's transient behavior when it is making a transition between operation and shutdown (**Figure 4**). It's easy to determine peak voltages and to quickly reset the bar graph between measurements. Record the peak voltages in decibels relative to 1V, or K_{CP}.

This test allows comparison between similar parts and yields a repeatable, objective result. Ensure that the test equipment is linear with any input magnitude. For instance, the peak reading when testing with a 1-mV impulse response should be 40 dB lower than that of a 100-mV impulse of the same pulse width (see **sidebar** "Calibrating equivalent equipment").

You could use an oscilloscope with some external filtering for this measurement, but experience shows that the typical level of click and pop for quality headphone amps is approximately 1 mV, which can be challenging to accurately estimate on most scopes. Testing higher voltage devices, such as high power amplifiers, may be possible using this approach.

Part-to-part variation likely yields slightly different results, so before harshly judging a part that performs poorly, test more than one device to get a feel for the variation. In a competently designed, dc-coupled headphone amp, most of the click and pop is proportional to input offset voltage, which

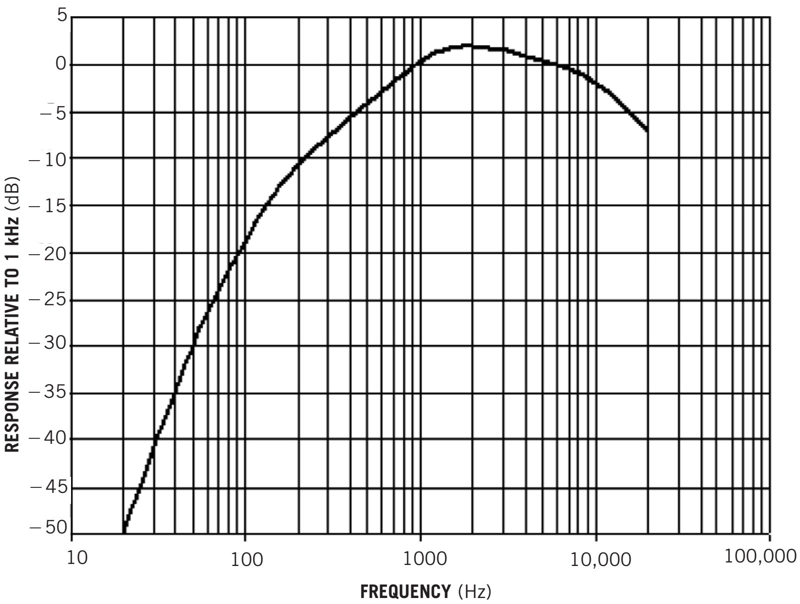
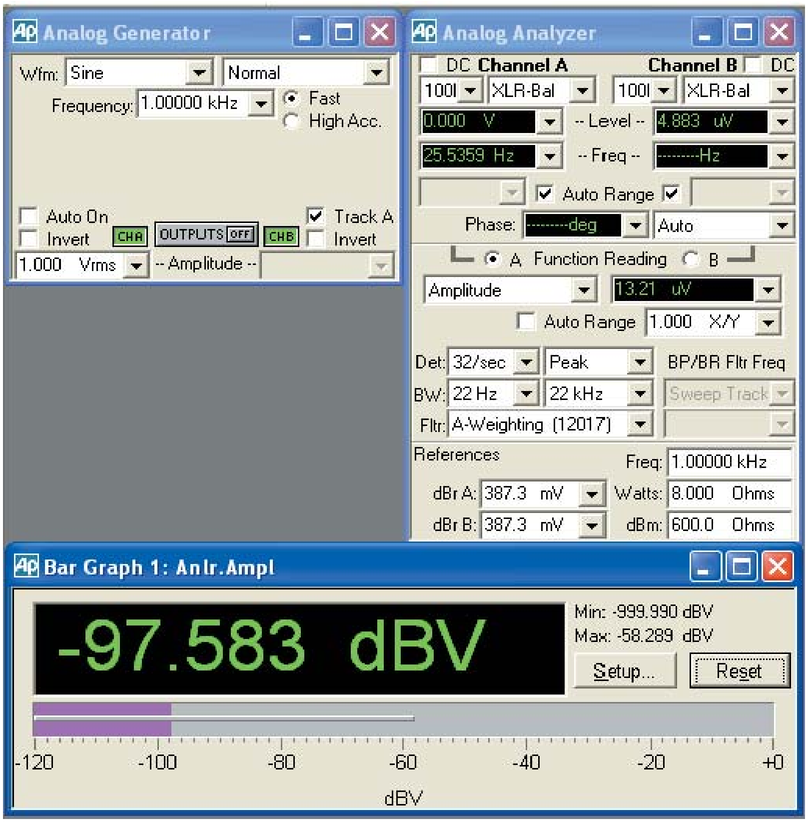


Figure 3 Designers often use the frequency response of the A-weighted filter for noise measurements, because the frequency balance approximates the ear's sensitivity. Note that the filter transfer function is unity gain (0 dB) at 1 kHz and attenuates the frequency extremes.



Wfm: Sine Normal
Frequency: 1.00000 kHz ● Fast ○ High Acc.
☐ Auto On ☑ Track A
☐ Invert ☐ Invert
1.000 Vrms -- Amplitude --

☐ DC Channel A Channel B ☐ DC
100l XLR-Bal 100l XLR-Bal
0.000 V -- Level -- 4.883 uV
25.5359 Hz -- Freq -- --------Hz
☑ Auto Range ☑
Phase: --------deg Auto
● A Function Reading ○ B
Amplitude 13.21 uV
☐ Auto Range 1.000 X/Y
Det: 32/sec Peak BP/BR Fltr Freq
BW: 22 Hz 22 kHz Sweep Track
Fltr: A-Weighting (12017)
References Freq: 1.00000 kHz
dBr A: 387.3 mV Watts: 8.000 Ohms
dBr B: 387.3 mV dBm: 600.0 Ohms

-97.583 dBV
Min: -999.990 dBV
Max: -58.289 dBV

Figure 4 The Audio Precision System Two click and pop test GUI shows that as the audio amplifier cycles in and out of shutdown, the bar graph will record the peak voltage present at the output of the DUT. The maximum reading is the peak voltage that the system measures. Select the reset button to reset the bar graph for each shutdown transition.

varies among parts unless you trim or otherwise remove it. To ensure consistent results when fully characterizing a part, you should repeatedly test the transition to and from each mode of operation. You can then calculate an average value. For a part that will enter production, it is advisable to test more than one part. Test all channels of a stereo or multichannel device.

AS THE AUDIO INDUSTRY CONTINUES TO EVOLVE IN RESPONSE TO CONSUMER DEMAND, OTHER SEMICONDUCTOR SUPPLIERS SHOULD CONSIDER ADOPTING THE DEFINED K_{CP} PARAMETER.

Consider this absolute voltage level of click and pop in the context in which the user will employ the amplifier. For example, suppose that you characterize a device that produces a −50-dBV transient when going into shutdown. If the DUT is a 50W/8Ω power amplifier, full scale will be 29 dBV peak. Hence, the ratio of the perceived click to the maximum peak voltage that the amplifier can deliver is $-(29-(-50))=-79$ dB, compared with peak signal. On the other hand, if the DUT is a 20-mW/16Ω headphone amplifier, full scale will be around −1.9 dBV peak, producing a less impressive ratio of −48.1 dB relative to peak volts.

Maxim separates audio tests into two categories, to rationalize the measurements. Referring to **Table 1**, Item 1 (power-up) and Item 2 (power-down) are Category A. You can usually assume that, for normal operation, any Maxim part with a shutdown function has mode transitions that the shutdown pin or register bit controls when you apply power. Items 3 and 4, Category B measurements, more closely represent normal use. Category A does not represent normal usage, so it is relevant only when measuring parts that you cannot be shut down under software control.

SETTING PERFORMANCE LEVELS

This method for deriving an objective figure of merit regarding click and pop behavior in turn allows you to compare the performance of parts claiming click and pop-suppression capability. You still need to decide how good is "good enough." Consider the following situation: After testing two headphone amplifiers using this method, you obtain repeatable results in which the figure of merit for Category B click and pop suppression is −59 dBV for the first amplifier and −61 dBV for the second.

Is the second device much quieter than the first device, or are both sets of results acceptable? The measurement is objective, but the interpretation of acceptability remains subjective. The level of click and pop suppression deemed acceptable or even detectable depends on a number of variables, including the expected headphone/speaker efficiency, the typical distance of the transducer from the listener, the rate at which shutdown is cycled, and the assumed level of background noise when listening.

The results for Category B click and pop tests on Maxim headphone amplifiers may provide a benchmark (**Table 2**). All tests use a 32Ω resistive load, and each K_{CP} number represents the average of four samples of each part.

As the audio industry continues to evolve in response to consumer demand, other semiconductor suppliers should consider adopting this method and the defined K_{CP} parameter. A forum for further discussion on this article is available at www.maxim-ic.com/TechSupport/Groups/audio.htm.□

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