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).
Click and pop measurements

Design feature

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.

<table>
<thead>
<tr>
<th>TABLE 1—TRANSIENT NOISE EVENTS IN AMPLIFIERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Powered up (power applied) Category A</td>
</tr>
<tr>
<td>2. Powered down (power removed) Category A</td>
</tr>
<tr>
<td>3. Brought out of shutdown (power applied previously) Category A</td>
</tr>
<tr>
<td>4. Forced into shutdown (power still applied) Category B</td>
</tr>
</tbody>
</table>

### Deriving an Objective Figure of Merit

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

### Table A—Audio Precision System Two Calibration Results

<table>
<thead>
<tr>
<th>$V_{in}$ (mV p-p)</th>
<th>$V_{theoretical}$ (dBV)</th>
<th>$V_{reading}$ (dBV)</th>
<th>A-weighting calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-60.000</td>
<td>-66.295</td>
<td>6.295</td>
</tr>
<tr>
<td>5</td>
<td>-46.021</td>
<td>-52.391</td>
<td>6.370</td>
</tr>
<tr>
<td>10</td>
<td>-40.000</td>
<td>-46.186</td>
<td>6.186</td>
</tr>
<tr>
<td>20</td>
<td>-33.979</td>
<td>-39.883</td>
<td>5.904</td>
</tr>
<tr>
<td>40</td>
<td>-27.958</td>
<td>-34.120</td>
<td>6.162</td>
</tr>
<tr>
<td>60</td>
<td>-24.437</td>
<td>-32.140</td>
<td>7.073</td>
</tr>
<tr>
<td>80</td>
<td>-21.938</td>
<td>-30.791</td>
<td>8.853</td>
</tr>
<tr>
<td>100</td>
<td>-20.000</td>
<td>-28.747</td>
<td>8.747</td>
</tr>
</tbody>
</table>

### 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.

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...
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.

**Figure 3**

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
Click and pop measurements

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.

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 \(-50\,\text{dBV}\) transient when going into shutdown. If the DUT is a 50W/8\(\Omega\) 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 \(-29-(\text{-50})=-79\,\text{dB}\), compared with peak signal. On the other hand, if the DUT is a 20-mW/16\(\Omega\) headphone amplifier, full scale will be around \(-1.9\,\text{dBV}\) peak, producing a less impressive ratio of \(-48.1\,\text{dB}\) 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 \(-59\,\text{dBV}\) for the first amplifier and \(-61\,\text{dBV}\) 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 32\(\Omega\) resistive load, and each MPS 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/Tech Support/Groups/audio.htm.

**Authors’ biographies**

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