Application Note

TAS27xx Introduction to Click and Pop Noise Measurement in Class-D Audio Amplifiers

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ABSTRACT

This application note outlines an introduction to click and pop noise in Class-D audio amplifiers, and methods to measure and optimize click and pop noise for TAS2780, TAS2781, and TAS2764 devices.

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Trademarks

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1 Introduction

Click and pop noise refers to an undesired transient audible artifact, which gets played on the speaker, usually during power-up and shutdown of the speaker driver (in this case, the Class-D audio amplifier). Click and pop noise can occur even if the audio amplifier receives no input and isn't playing any music at the output (idle channel condition).

Pop can occur irrespective of the type of amplifier driving the speaker. However, it is usually lower in more linear amplifiers such as Class-A or Class-AB as compared to Class-D. The Class-D amplifier outputs are pulse width modulated (PWM) based switching to achieve high efficiency at higher output powers. A settled Class-D amplifier output voltage frequency spectrum comprises of the gained-up audio input signal frequency (Fin) in audio band (20-20KHz) as well tones around switching frequency (Fsw), and the multiples.

When the device is in idle channel, the differential voltage across the speaker (in audio band), after the Class-D output is settled is just the RMS noise voltage of the amplifier. This can be the *Idle channel noise* of 32uV A-weighted on TAS2780/81 (Refer Electrical Characteristics in data sheet).

However, during start of the PWM from shutdown state, the differential error pulses start to build at Class-D output from zero error voltage hence resulting in a spectral energy that leaks into audio band. A similar scenario occurs due to stop of PWM pulses. Click and pop can occur at the output of the Class-D amplifier irrespective of the modulation scheme due to amplifier output differential offset (Output offset voltage Vos as per data sheet) and amplifier output settling related artifacts.

Figure 1-1 shows a sample start and stop of an LSR modulated Class-D PWM switching waveform.

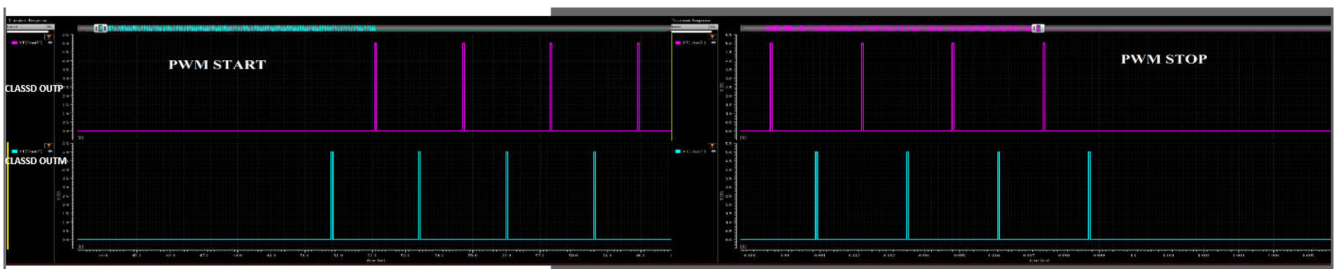

Figure 1-1. Sample LSR Modulated Class-D PWM Output Switching Waveforms at the Start and Stop

2 Measurement Methodology

Pop is effectively quantified as an output *peak* voltage that gets played across the speaker before settling of the amplifier output, during power-up and power-down. Since the audio band energy (20-20KHz) at Class-D output is only of interest, there are audio band pass filters used at the Class-D output used for measurement. Further an A-weighting filter, which is used to mimic the human ear response, is cascaded with these preceding filters.

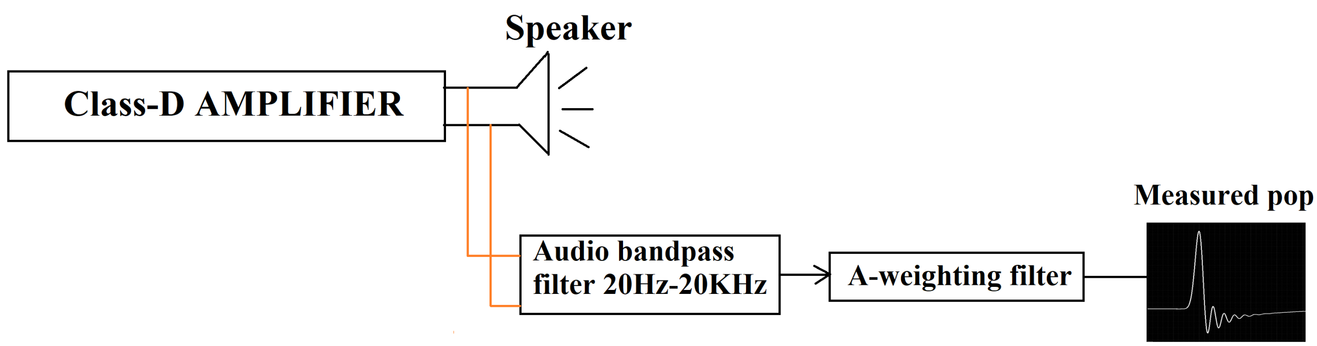

Figure 2-1. Pop Measurement

The measured pop is quoted as a voltage across the speaker (either in mV or dBV).

For example, 1mV pop refers to -60dBV click and pop:

$$20*log10(le-3) = -60dBV \qquad (1)$$

The typical click and pop performance measured on TAS2780, for example, is 0.8mV or -62dBV (Referred to as Kcp in Electrical Characteristics section 6.5 of data sheet)

Figure 2-2 shows the measured Class-D output waveform and measured pop due to PWM start and stop.

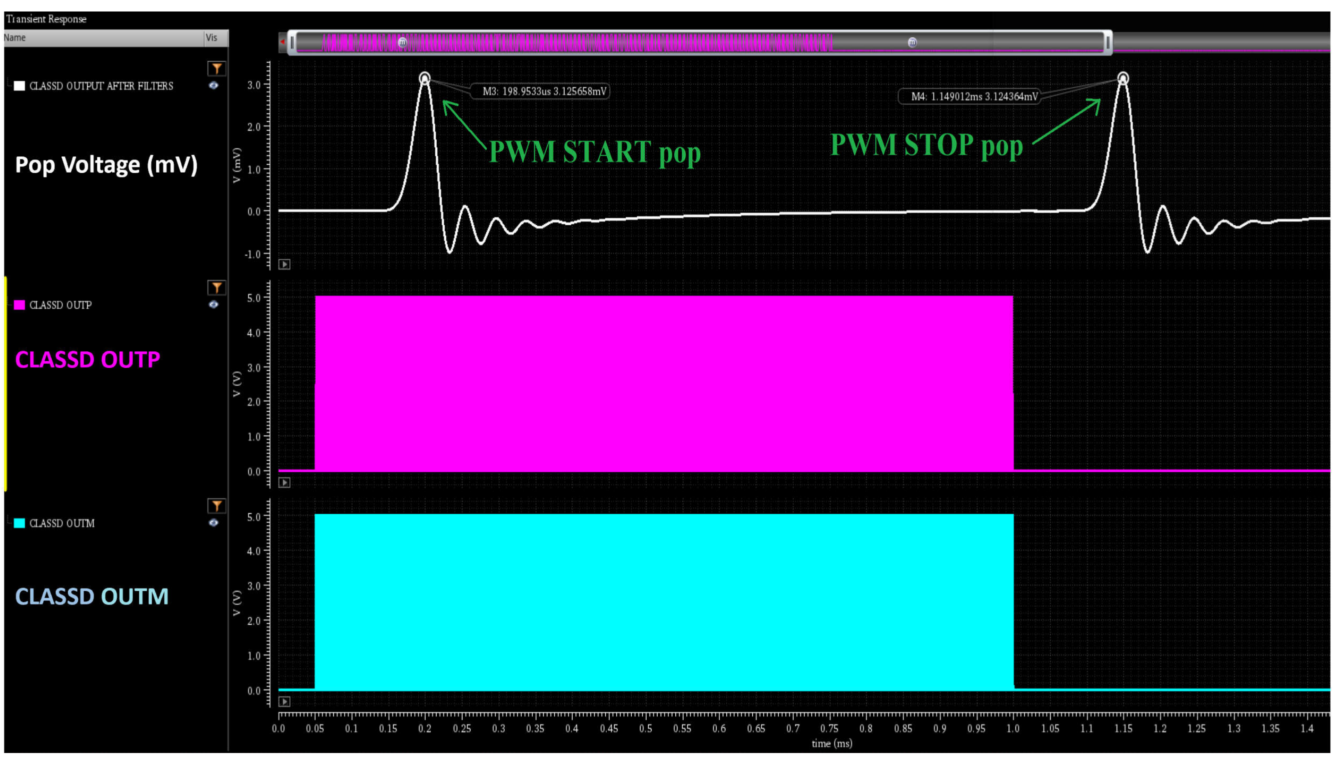

Figure 2-2. Measured Pop Due to Start and Stop of Class-D PWM

3 Introduction to Noise-gate and Pop in Class-D Amplifiers

Past literature studying the audibility of click and pop to the human ear clearly show that pop is an perceptible artifact and hence is critical to minimize the same (Reference: Click and Pop Measurement Technique). Since click and pop noise voltage can be played across the speaker, and hence perceptible to the user. Achieving low pop is critical for best user audible experience.

In TAS27xx family of amplifiers there exists a *noise gate feature* (NG) (8.4.2.7 on TAS2780 data sheet), in which the Class-D amplifier is dynamically shutdown and turned back on based on the audio input received. For example, if the Noise gate threshold is set to -120dBFs the Class-D automatically shuts down if the audio input to the device remains lower than this threshold for >50 ms (NG hysteresis time) duration. The moment an audio sample greater than the NG threshold is received by the device, the device automatically exits NG and the Class-D amplifier immediately turns on to play the corresponding sample faithfully at the Class-D output. This feature allows for improved amplifier efficiency for audio profiles where there are long durations of silence. Consequently, since repetitive shutdown of the amplifier happens during entry and exit from noise gate, it is further important that click and pop noise remain low.

4 Causes of Pop in TAS27xx family of Class-D Amplifiers

The following events on TAS27xx family of amplifiers can lead to a very low, regulated click and pop at the Class-D output:

- Active to Software shutdown
- Shutdown to Active mode
- Noise gate entry and exit (As per audio input and NG threshold (Note: Increasing Noise gate threshold higher than default settings can result in higher click and pop)
- Idle channel detect entry and exit

The following events can trigger very high or uncertain pop:

- Software or hardware reset.
- Fault conditions in the device such as clock error, over-current error, over-temperature error, and so on. (These conditions can result in very high pop due to abrupt shutdown).
- Abrupt dips and overshoots in the supply beyond data sheet limits.
- Incorrect hardware/software configuration of the device.

5 Click and Pop Using TAS27xx

A method to minimize click and pop noise is to prevent an abrupt build-up of the differential error voltage across the speaker. This is done by soft-stepping of the differential Class-D output voltage. This is similar to the concept of volume ramping the audio signal.

One key technique used by TI to minimize pop is using the Y-bridge feature in TAS27xx family of devices. In the Y-bridge mode of operation, the Class-D amplifier power stage switches on VBAT supply rather than PVDD for lower audio inputs. This is done to reduce switching losses in the power stage and improve the device efficiency at lower power. This feature also significantly helps reduce pop. During power-up, for example, the Class-D always switches out of VBAT supply and switches into PVDD later in the power sequence. This helps minimize the differential error built up across the speaker. Similarly, before shutdown the Class-D enters VBAT switching to reduce pop.

TI also uses several patented soft-stepping techniques to build-up the Class-D output PWM pulses to make sure smooth build-up of differential voltage across the speaker. Table 5-1 summarizes the click and pop performance in TI's TAS27xx family of devices.

Table 5-1. Click and Pop Performance in TAS27xx

Device	Click and Pop (Typical)	Condition (Measured as per Data Sheet)
TAS2764	1mV	TA = 25 °C, PVDD = 12V, VBAT1S = 3.8V, AVDD = 1.8V IOVDD =1.2V, RL = 4Ω + 16µH fs = 48kHz, Gain = 21dBV, SDZ = 1, EDGE_RATE[1:0]=00, NG_EN=0, EN_LLSR=1, PWR_MODE1, Measured filter free as in Section 7 (unless otherwise noted).
TAS2780	0.8mV	TA = 25 °C, PVDD = 18V, VBAT1S = 3.8V, AVDD = 1.8V, IOVDD =1.8V, RL = 4Ω + 15µH, fs = 48kHz, Gain = 21dBV, SDZ = 1, NG_EN=0, EN_LLSR=0, PWR_MODE1(2), measured filter free as in Section 7 (unless otherwise noted).
TAS2781	0.8mV	TA = 25 °C, PVDD = 18V, VBAT1S = 3.8V, AVDD = 1.8V, IOVDD =1.8V, RL = 4Ω + 15µH, fs = 48kHz, Gain = 21dBV, SDZ = 1, NG_EN=0, EN_LLSR=0, PWR_MODE1(2), measured filter free as in Section 7 (unless otherwise noted).

6 Click and Pop Measurement Technique Using AP v6.0. 2

Figure 6-1 shows a pictorial representation of the hardware connection required for click and pop measurement. DUT refers to the amplifier driving the speaker.

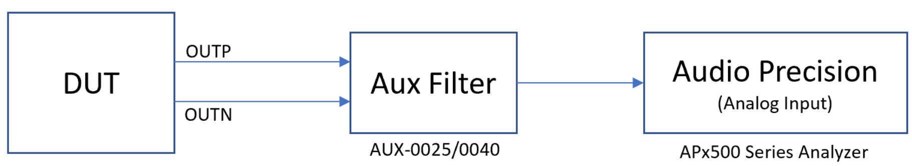

Figure 6-1. Hardware Configurations Required for Measurement of Click and Pop

6.1 Measurement Setup

APx555B Series Audio Analyzer equipment is used for this measurement along with*APx500 Measurement Software Version 6.0.2*. DUT outputs are connected to this Analyzer input through a passive filter *AUX-00225/0040* which is a switching amplifier measurement filter to reduce out-of-band switching signal components before AP measurements. A pictorial representation of the setup is given in Figure 6-1 for reference.

6.2 Filter Settings

AP is configured with the filter settings as shown in Figure 6-2.

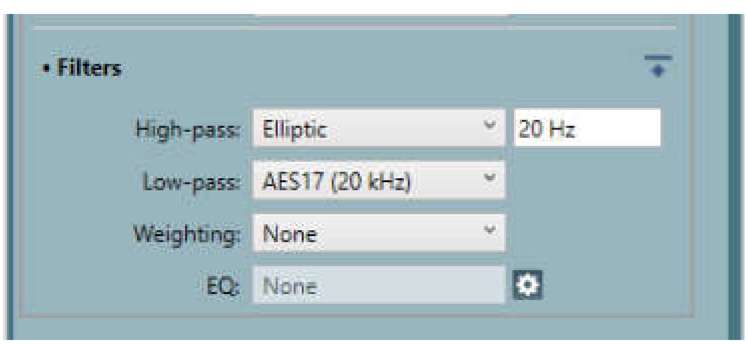

Figure 6-2. AP Filter Settings

High-Pass Filter (Elliptic 20Hz): 20Hz, 5-pole elliptic high-pass filter is chosen. The filter has a passband ripple of 0.01dB and a sharp roll-off to -60dB.

Low-Pass Filter (AES17 20kHz): This filter is an 8-pole elliptic filter with a corner frequency at 20kHz, satisfying the AES17 recommendation for converter measurements and other measurements in the presence of high out-of-band noise. When this filter is selected, the ADC sample rate is set to 48kHz.

Note

Elliptic filter is chosen over the Butterworth filter as the Elliptic filter has a better brick wall response compared to a Butterworth filter and offers more accurate representation of audio pop. Comparison of Elliptic and Butterworth Filter responses is given in Figure 6-3 and Figure 6-4 for reference.

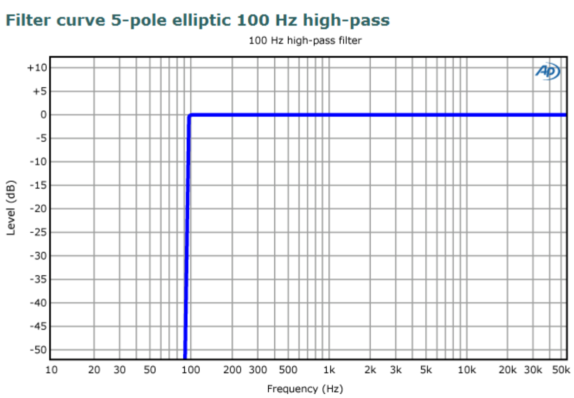

Figure 6-3. 100Hz Elliptic Filter Response

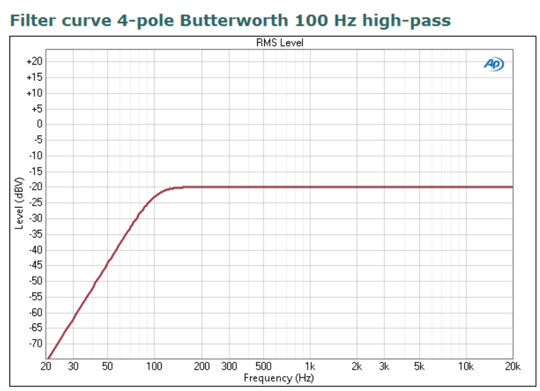

Figure 6-4. 100Hz Butterworth Filter Response

6.3 Data Capture Settings

For the click and pop measurement, continuous capture of *Peak Level* is done over a fixed duration of time (for example, 30 seconds) through *Measurement Recorder* option in APx555 measurement software. This data is stored in a file and post-processing is done over the stored data to get A-weighted results.

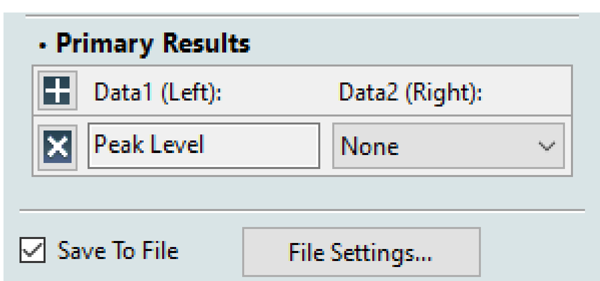

Figure 6-5. Peak Level Measurement Through Measurement Recorder

The *Save to File* option in the *Measurement Recorder* option needs to be enabled as shown in Figure 6-6.

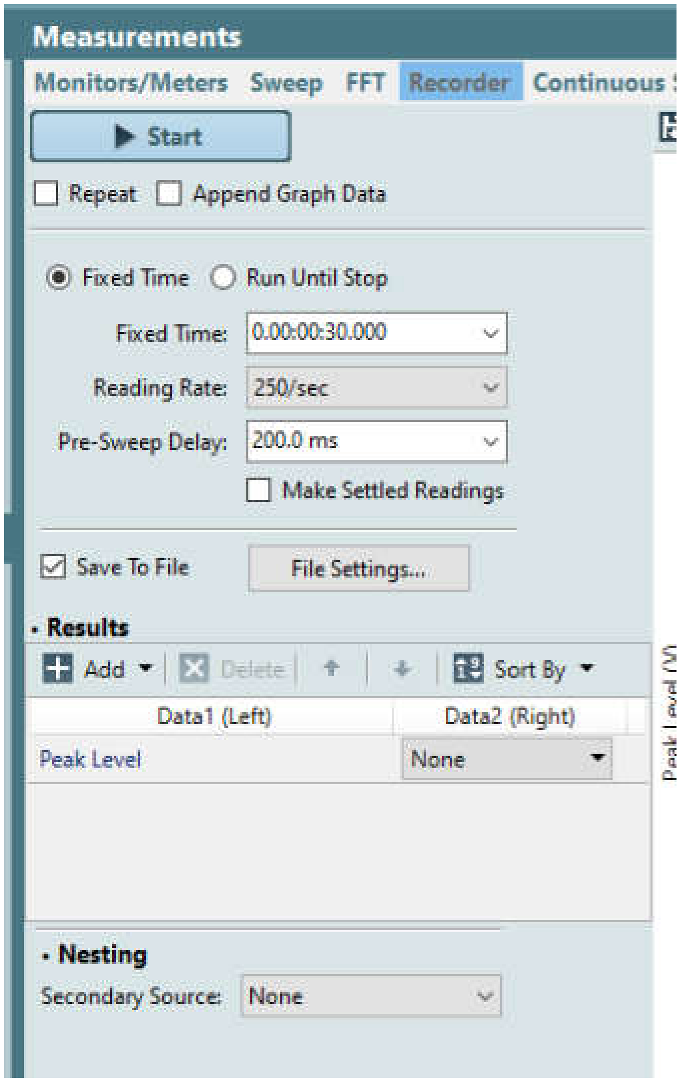

Figure 6-6. Save to File Option to be Enabled

Click the File Settings button and a pop-up window appears as shown in Figure 6-7. In this pop-up window, configure a folder path for the *Measurement Recorder* to save the data. And select file format as *Extensible Multi-channel PCM* and Bit depth as 24 bits.

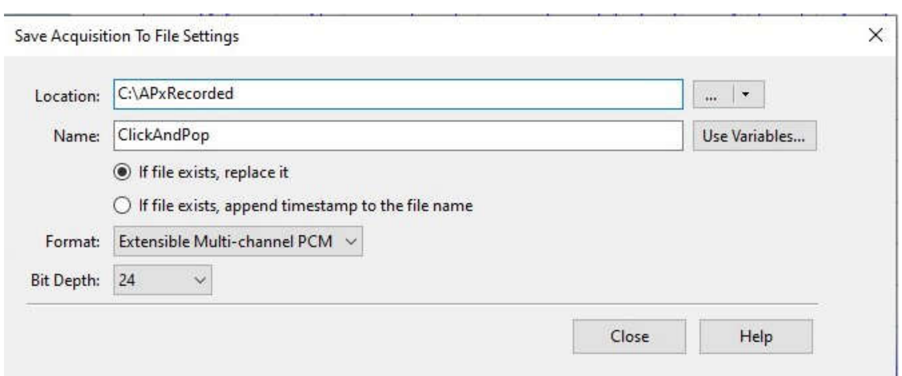

Figure 6-7. Save to File Setting Options

6.4 Auto Range Settings for Pop Measurement

A click and pop event is such a fast transient event that the auto-range inside the audio measurement system does not have enough time to select the correct range. For this reason, auto-range needs to be disabled and the range selected must be high enough that the input signal does not clip in the audio measurement system and low enough that an adequate resolution is maintained.

For the APX555, there are eleven range options available in audio precision. These are the same for both the unbalanced and balanced analog inputs:

- 0 Vrms to 310 mVrms
- 310 Vrms to 620 mVrms
- 620 Vrms to 1.25 mVrms
- 1.25 Vrms to 2.5 mVrms
- 2.5 Vrms to 5 mVrms
- 5 Vrms to 10 mVrms
- 10 Vrms to 20 mVrms
- 20 Vrms to 40 mVrms
- 40 Vrms to 80 mVrms
- 80 Vrms to 160 mVrms
- 160 Vrms to 320 mVrms

Figure 6-8 shows that *Auto Range* is unchecked and a manual range of 310mVrms is chosen as Input Range.

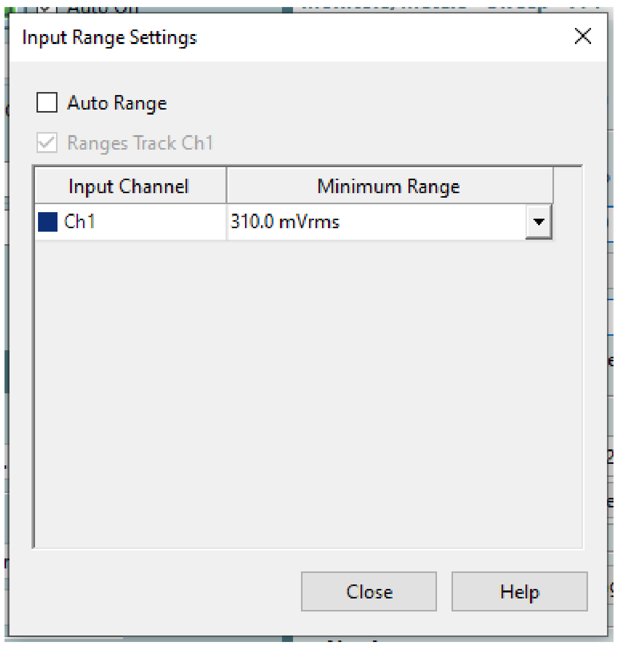

Figure 6-8. Auto Range is Disabled and a Fixed Range of 310mVrms is Chosen

With all the settings mentioned previously, save the AP project file in a location. This file is used with *APX Sound Level Meter Utility* tool for the Click and Pop measurement.

6.5 ASI or I2S Configurations for Pop Measurement

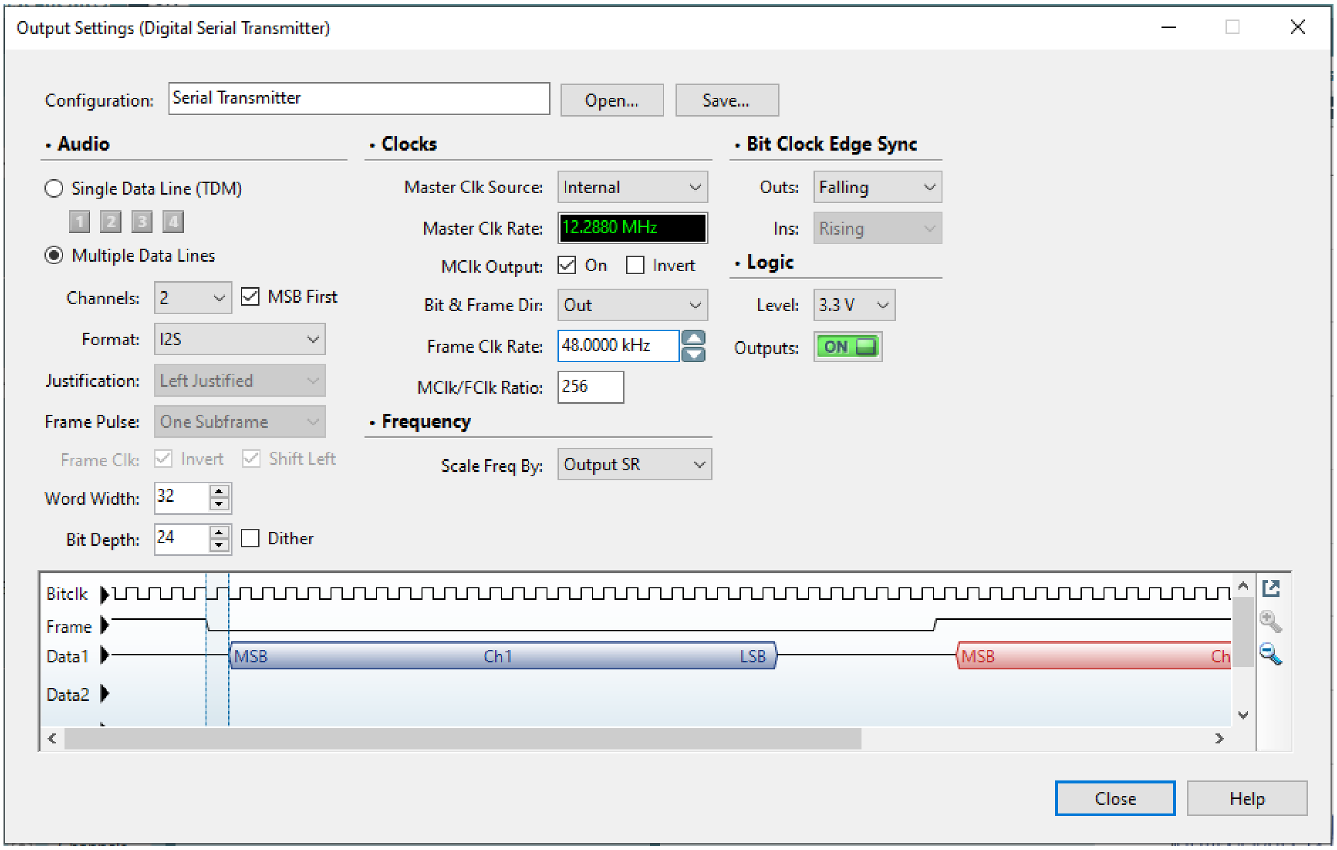

Figure 6-9. Data and Clock Configurations

In the AP project file, along with other settings, configure ASI or I2S settings required for the proper operation of DUT. A typical configuration used for the family of TAS27xx devices is shown in Figure 6-9.

6.6 APx Sound Level Meter Utility

APx Sound Level Meter Utility (Version 6.0.0) is a tool from Audio Precision which is used along with APx500 series analyzer to perform click and pop measurement. This utility takes advantage of the file recording capability of the APx500 software. This method of click and pop measurement is preferred over any other discrete interval measurement methods because,in a discrete measurement method, even at a relatively fast measurement rate of 250 per second, a transient click or pop event can get missed between acquisitions. But in this method, by making a digital recording at a 48kHz sample rate, we can be sure that any audible transients can get captured.

APx Sound Level Meter Utility comes-up with an interface as shown in Figure 6-10. Click the *Load Project* button in the interface and select the AP project file path which was stored with all required configuration needed for the click and pop measurement.

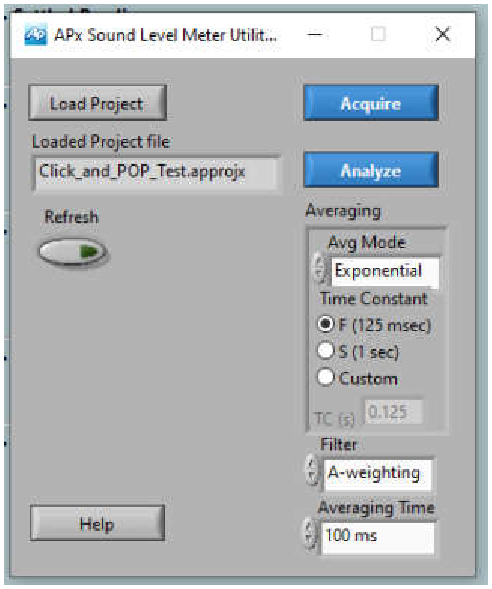

Figure 6-10. APx Sound Level Meter Utility Window

6.7 Data Acquisition

Click the Acquire button on the utility to start recording the file. The recording runs for programmed duration as per the Project file and then stops. During this time, in parallel, turn ON and OFF the device under test to manipulate the clicks and pops scenario. The acquisition happens for the programmed Fixed Time saved in the AP project file (Example: 30 sec). Once the recording gets over, click the Analyze button. In the example given in Figure 6-11, 50 cycles of *Turn On* and *Turn Off* of the device was exercised in parallel, when the AP was doing the acquisition for a fixed duration of 30 seconds. Figure 6-12 shows the peak level getting captured during this period.

6.8 Interpreting Click and Pop Waveforms

This window displays Non A-Weighted raw data at a reading rate of 250 per second. This is the maximum reading rate option available in AP. By looking at the data, we can understand that a maximum peak level of approximately 1.4mV got recorded over the complete acquisition period. Since this measurement was done by repeatedly powering up and powering down the device, every alternate pop is due to power up or power down. Post power up the amplifier output offset voltage is high pass filtered (20Hz in AP) and we observe a falling settling transient voltage from 200uV to 100uV before shutdown.

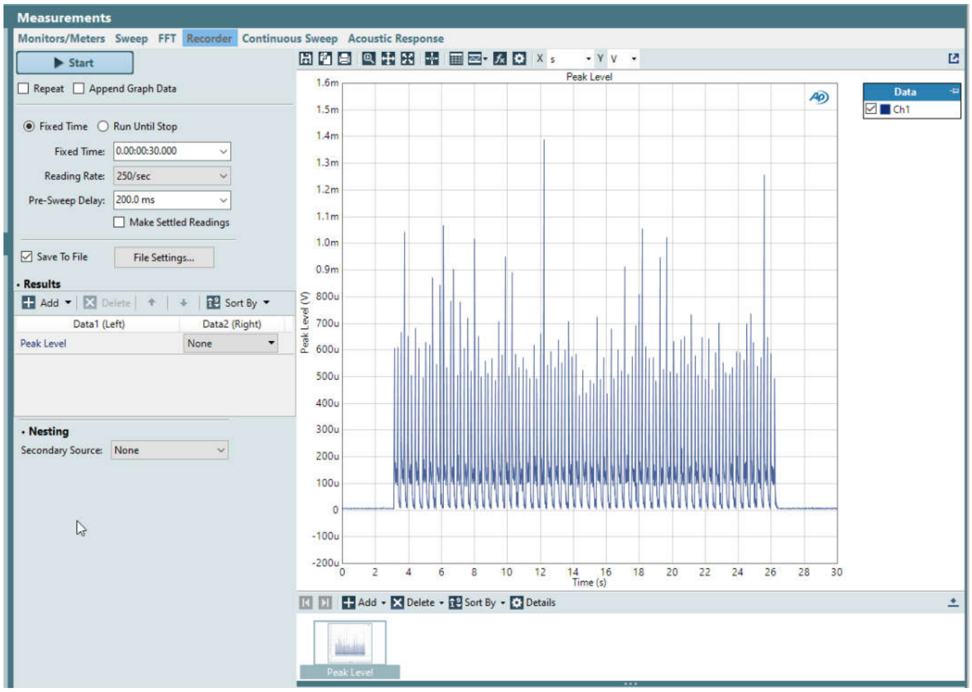

Figure 6-11. Measurement Recorder Window – Capture

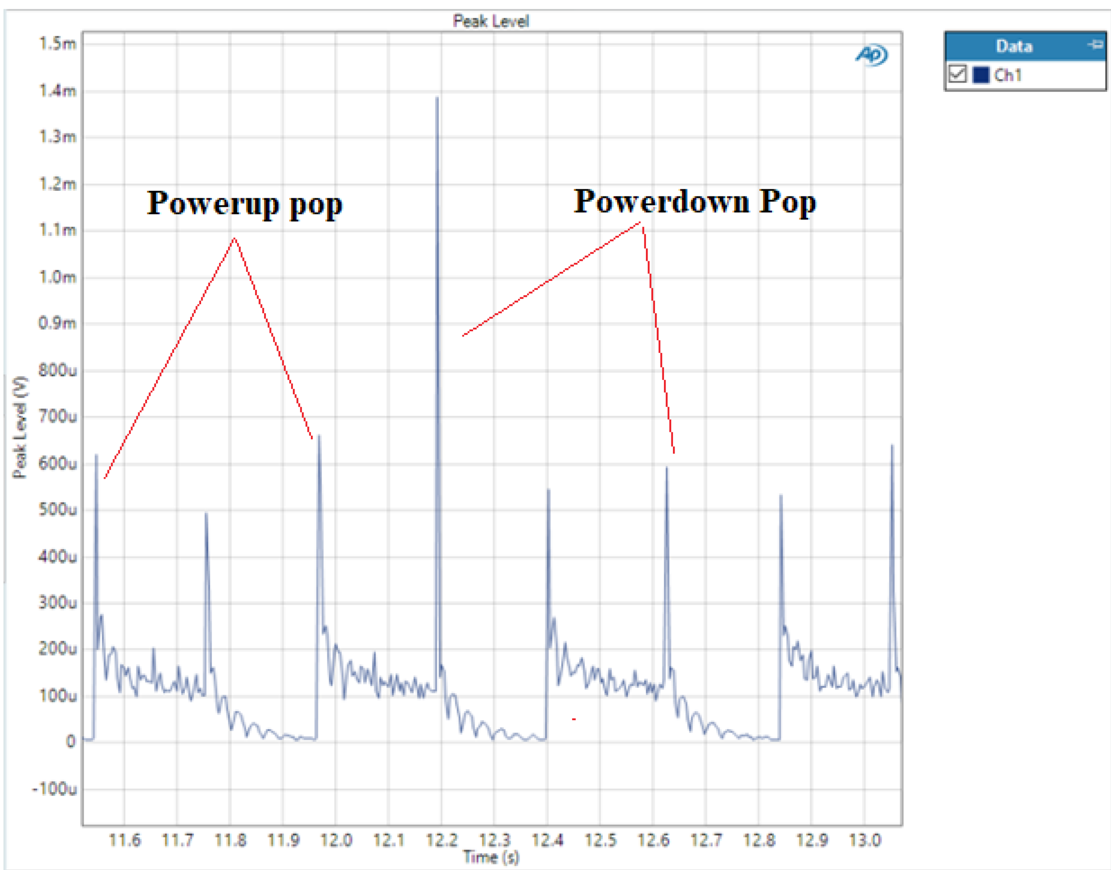

Figure 6-12. Measurement Recorder Window – Zoomed Around Max. Peak Level

6.9 Post Processing of AP Waveforms

Once the acquisition is over, click the Analyze button on the APX Sound Level Meter (SLM) utility tool. This opens up another window titled Filter and Average Waveforms with three views: the original data, the data after it has been passed through an optional A weighting filter, and the data after it has been averaged. If you change the filter, time constant, and averaging settings in the window, the graphs automatically redraw. SLM utility takes the raw data *saved as file* by the measurement recorder, processed the data (Filtering and Averaging), and displayed the data as two different waveforms along with original waveform in the window as shown in Figure 6-13.

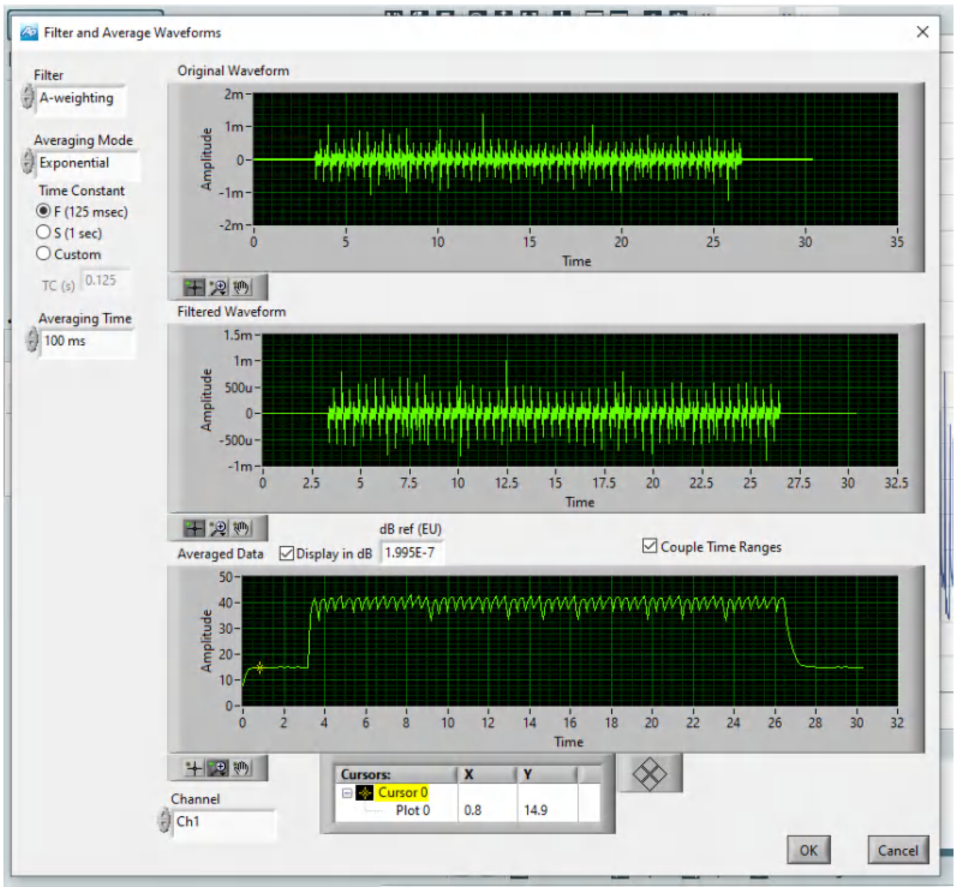

Figure 6-13. Filter and Average Waveform Window – SLM Utility Analyze Output

6.10 A-Weighted Click and Pop Numbers

For the click and pop measurement, only the Filtered Waveform section is important. You can discard the Averaging Mode, Averaging Time, and Averaged Data sections as these are not relevant to the click and pop measurement. Please make sure to choose *A-weighting* as *Filter* option in the window. This applies the *A-Weighting* filter on the *Original Waveform* and the resulted *A-Weighted Waveform* appears in the *Filtered Waveform* section. In Figure 6-14, zoom in around the Maximum peak level, and analyze both the original and A-weighted waveform outputs.

The original waveform is displaying a max peak level of approximately 1.4mV (similar to the capture in Measurement Recorder Window Output). At the same instance, the A-weighted filtered waveform displays a max peak level of approximately 1.1mV.

Figure 6-14. Filter and Average Waveform Window – Zoomed Around Max. Peak Level

6.11 Exporting the A-Weighted Numbers

As shown in Figure 6-15, you can export the A-weighted results to an excel and do a detailed analysis as well. To do this, right click on the *Filtered Waveform* data and select *Export* and choose *Export to Excel*. This opens the *A-Weighted Filter* output in excel.

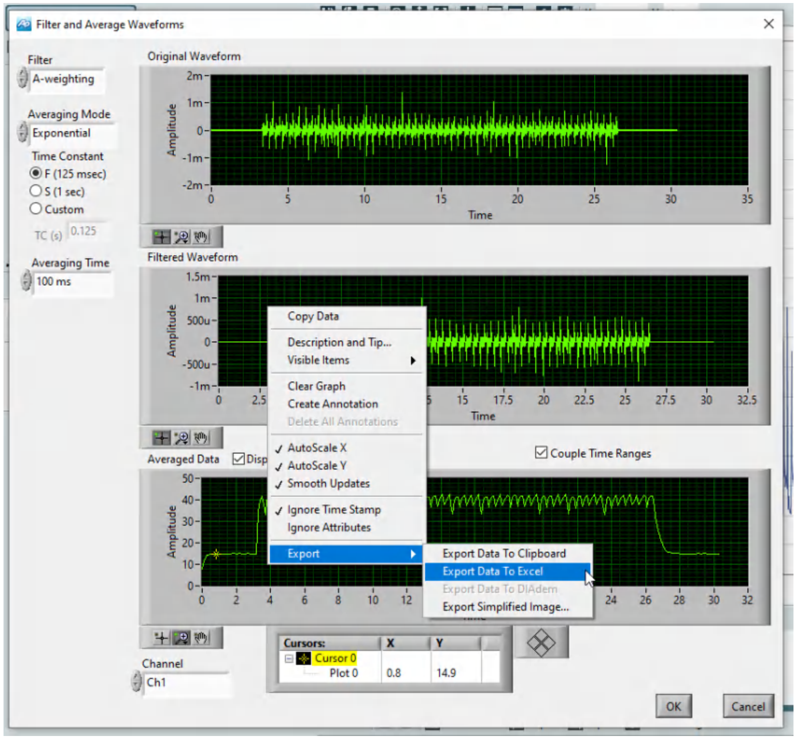

Figure 6-15. Exporting A-Weighted Pop Results From APx

7 Noise-Gate Pop and Measurement Technique Using APx

To measure the noise gate (NG) power up and power down pop of the device, a repetitive audio input stimulus slightly higher than the noise gate threshold is given to excite the device and exit NG (wake up). This is followed by a long period of silence greater than the NG hysteresis timer to allow the device to enter NG and shutdown. By default the NG threshold is at -120 dBFs in TA27xx amplifier product family.

An input stimulus such as this can be generated using a low frequency, low amplitude sine wave such as 1Hz with -119dBFs. This makes sure that the device exits from noise gate at the peak audio sample and enters into noise gate since the amplitude remains well below noise gate for long durations (> NG hysteresis of 5ms).

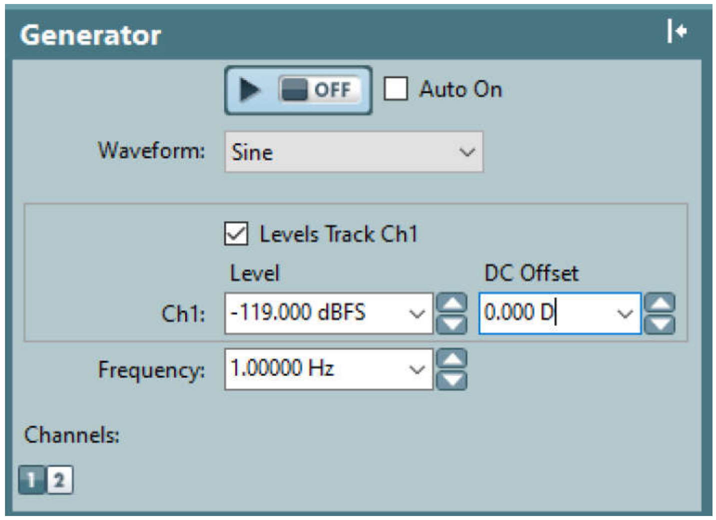

Figure 7-1. Sample Generator Excitation for Capturing Noise Gate Pop

Using Audacity or other software as well as excitation.wav waveform file can be generated and imported into AP, and played in the measurement recorder. If an external audio.wav file is used, the file has to be fed as input in APx as shown in Figure 7-2.

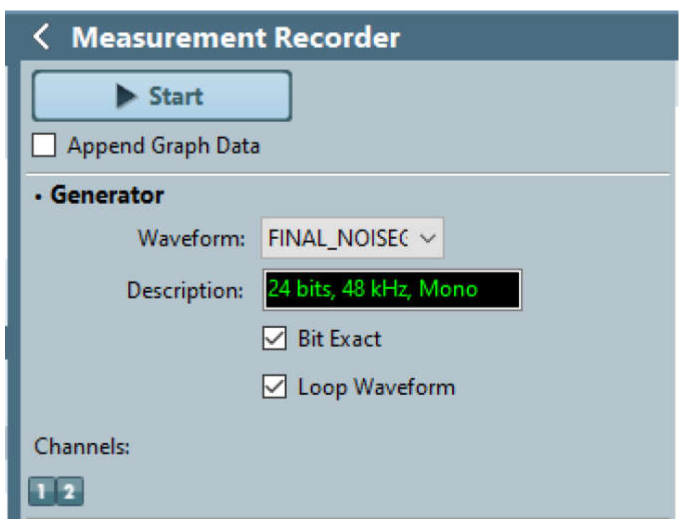

Figure 7-2. APx Configuration for Importing External .wav Excitation

All other filter settings, I2S configuration settings, and recorder sample rate settings remain the same.

8 Configuring TAS2764 for Improved Click and Pop Noise Performance

This section details the best device configurations required to reduce pop noise on TAS2764. In TAS2764, to optimize device click and pop performance, the recommendation is to force the device into idle channel mode before shutdown and exit out of the same prior to re-start.

The additional I2C configurations required for the same are as follows:

- w 70 00 fd
- w 70 0d 0d
- w 70 64 04 #force device into idle channel mode
- w 70 00 00 #page 0
- w 70 02 02 #software shutdown
- w 70 00 fd
- w 70 0d 0d
- w 70 64 00 #device exits from idle channel mode

8.1 Explanation

Pop minimization is done through forcing the device into idle channel mode before power down of the device and exiting from idle channel mode post power up. This is done to effectively stagger the shutdown pop in the device. This device optimization is already taken care In TAS2780 and TAS2781 in internal device power up or power down configurations. Figure 8-1 shows the click and pop measured on 1 device in Powermode1 Configuration of the device before and after applying the script.

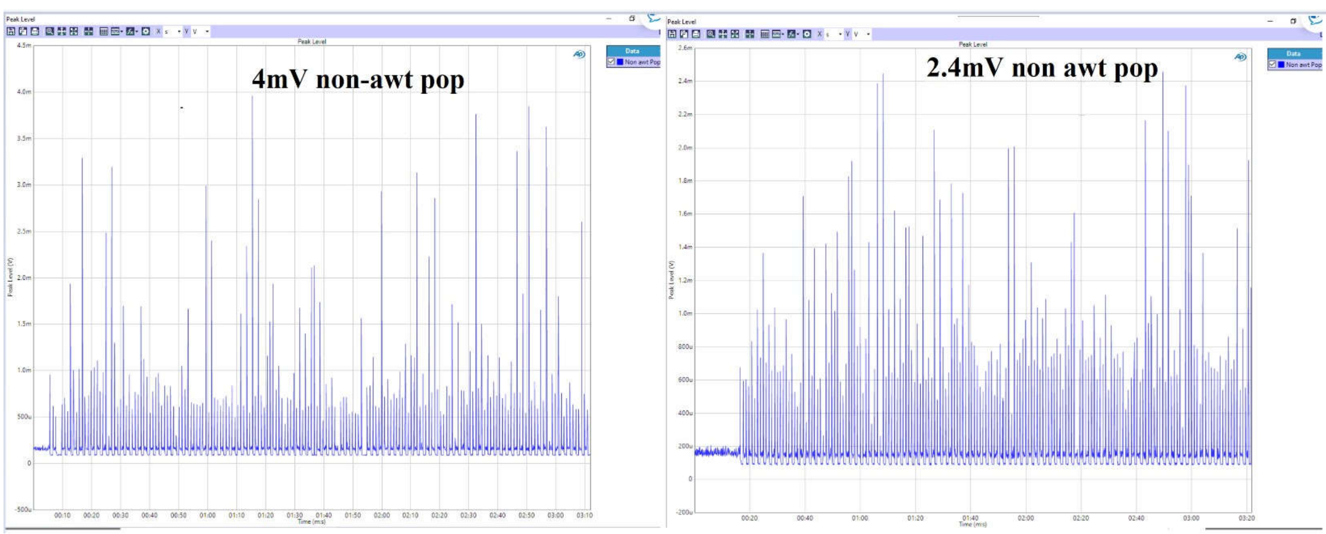

Figure 8-1. Hardware Configurations Required for Measurement of Click and Pop

9 Summary

This application note explains the fundamentals of click and pop in Class-D audio amplifiers. The application note introduces the measurement techniques as well as designed for configurations required in TAS27xx for achieving improved click and pop noise performance.

10 References

- Texas Instruments, *TAS2780 Digital Input Mono Class-D Audio Amplifier With Speaker IV Sense*, data sheet.
- Texas Instruments, *TAS2781 24-V Class-D Amplifier with Real Time Integrated Speaker Protection and Audio Processing*, data sheet.
- Texas Instruments, *TAS2764 Digital Input Mono Class-D Audio Amplifier With Speaker IV Sense*, data sheet.
- Texas Instruments, *Click and Pop Measurement Technique*, application note.

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