WHITE PAPER

Pop and Click Artifacts in PC Audio Systems

Pops and clicks are audible, undesirable noise artifacts that occur when an unintended analog signal is passed through to an audio output device (i.e., headphones, speakers, and so on). These unintended analog signals are typically produced when an audio input or output undergoes a state change, for example, during jack retasking or device power state (D3, D2, D1, D0) changes. These state changes often result in an instantaneous DC voltage shift on the input or output signal path. The DC voltage shift, if large enough in magnitude, will result in an audible artifact during playback or record events.

Instantaneous DC voltage shifts occur during typical PC system power state transitions: start-up, shutdown, suspend, and resume. The unipolar power supply architecture typically used in PC systems increases the probability that DC voltage shifts will result in audible artifacts.

Introduction

This document describes the common sources of pop and click artifacts in PC audio systems, presents solutions for minimizing these artifacts, and details the architecture advances that have been made in the IDT high definition audio (HDA) codec product line to improve pop and click performance.

Audio architecture overview

Unipolar power supply architecture

Currently, the majority of HD audio codecs are powered by a single analog voltage supply. This requires the codec's internal analog circuits to reference a virtual signal ground between the positive analog supply and ground. The DC value of this virtual signal ground (also known as virtual analog ground [VAG]) is typically 45 percent of the positive analog supply value. Because the internal analog circuits are referenced to VAG, a DC bias equal to VAG is present on all analog codec I/O pins. Figure 1 illustrates the virtual analog ground required to transmit an audio signal with a unipolar power supply and compares against the 0 V analog ground of a bipolar power supply circuit.

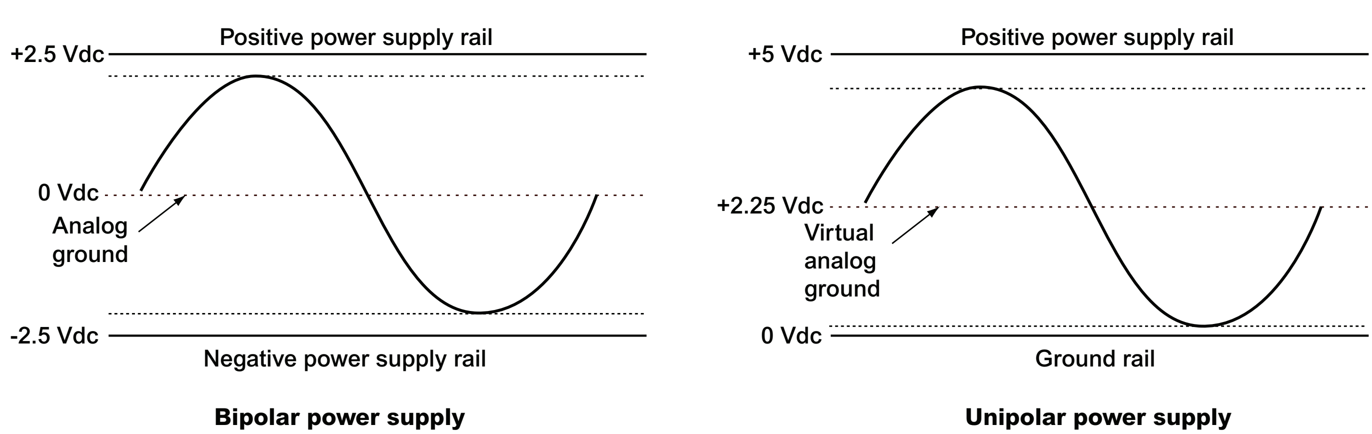

Figure 1. AC voltage swing for bipolar and unipolar power supplies

The device load (at the PC jack) is referenced to the system supply ground, rather than the codec virtual signal ground. This results in a voltage differential between the PC jack and the codec I/O pin. To block this DC voltage, an AC coupling capacitor is required between the codec I/O pin and the PC jack on all analog I/O signal lines. Figure 2 illustrates the AC coupling capacitor in a simplified analog output circuit.

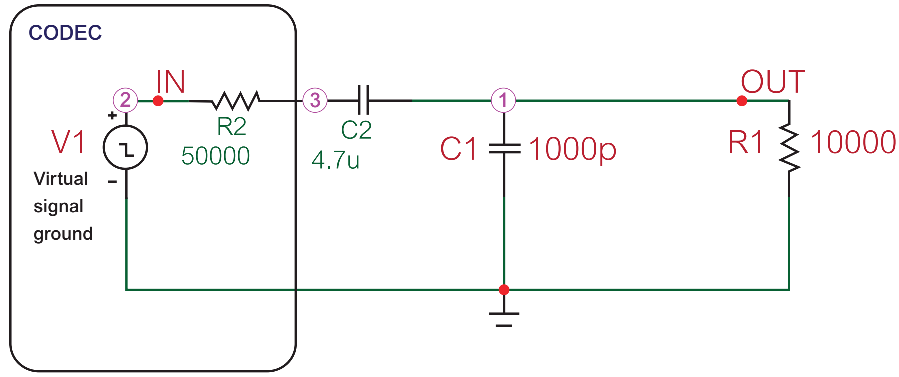

Figure 2. Simplified analog output circuit

R2 = Impedance of codec port in default, "OFF" state
C2 = AC coupling capacitor
C1 = ESD/EMI capacitor + parasitic capacitance
R1 = Output load

DC voltage shifts occur at the AC coupling capacitor (C2) during state changes of the codec I/O pins. The ability of the capacitor to charge and discharge appropriately determines whether audible pops and clicks occur. The severity of the pop/click artifact is a function of the voltage amplitude, slew rate, and gain present in the output path.

- For example, a voltage change with a 20 mS slew rate and 40 mV amplitude will result in an audible -28 dBV, 50 Hz signal across a typical audio load.
- The following factors should be used to determine whether a voltage shift will result in an audible artifact:
  - **Frequency range:** 20 Hz–20 kHz is the audio band for human hearing. Voltage slew rates of 5 mS–50 μS produce artifacts within this audible frequency range
  - **PC audio amplitude:** 1 Vrms is a common PC audio reference amplitude and dBV is decibels relative to 1 Vrms. Analyze pop severity by converting voltage shifts to dBV: 20 (log Vin/1 Vrms) = 'amplitude in dBV units'
  - **Audio load:** Consider the frequency response characteristics of the audio test load (i.e., headphones, speakers, and so on.)

Figure 3 shows a typical charge/discharge profile of the AC coupling capacitor during common state changes.

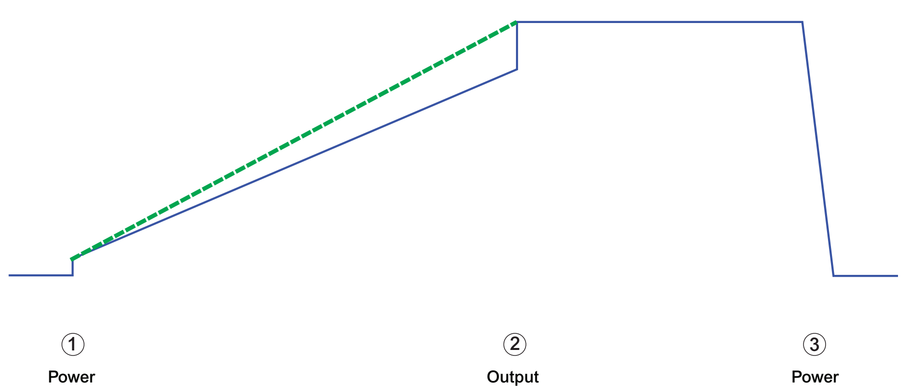

Figure 3. AC coupling capacitor charge/discharge profile

Blue = Voltage at AC coupling cap
Green = Virtual signal ground (VAG) inside of CODEC

Common sources of pop and clicks

System start-up/power on

During system start-up, power is applied to the codec (stage 1 in figure 3) when the analog supply is turned on. The ramp characteristics of the analog supply influence the DC voltage step seen at the AC coupling capacitor. Generally, the voltage step is small enough that any resulting artifact is not audible.

During the next major state change, the codec output is enabled by the audio software (sw) driver (stage 2 in figure 3). Between stage 1 and stage 2, the AC coupling cap and codec VAG will ramp to their highest voltage level. The ramp time of VAG is dependent on codec architecture and the value of the external capacitor on the codec VREF_FILT pin (pin 27 on IDT HDA codecs). The ramp of the AC coupling cap typically lags behind VAG and is dependent on capacitive value, and the source (R2) and load (R1) resistance values. If the codec output is enabled before the AC coupling cap is fully charged, an instantaneous DC voltage shift will occur at the AC coupling cap resulting in a potentially audible pop or click artifact at the signal output.

Since the ramp time of the AC coupling cap is dependent on capacitance and resistive values, different output circuits are susceptible to the varying severity of pops (assuming the time between power on and codec output port enable remains constant). Line out ports with smaller AC coupling capacitors (e.g., 3.3 µF) and 10K ohm loads will experience less severe DC voltage shifts and thus, less severe pops because the coupling capacitor will charge more quickly. Headphone ports with larger AC coupling caps (e.g., 220 µF) will experience large DC voltage shifts and more severe pops because the capacitor charges more slowly.

System shutdown/power off

When power is removed from the analog circuit of a codec (stage 3 of figure 3), the codec output pin—depending on signal conditions—may be at a higher potential than the discharging power supply rail. This condition will occur if the AC coupling capacitor is charged when power is removed, since the jack side of the capacitor is referenced to system ground. In this situation, if the codec output is enabled when power is removed, the electrostatic discharge (ESD) protection structures in the codec will turn on causing the codec pin to closely follow the analog supply voltage. The result is an instantaneous DC voltage shift at the AC coupling capacitor, causing a potentially audible pop or click.

Codec state changes

Audible pops and clicks can also be produced by DC voltage shifts that occur when the codec transitions between different operating states. For example, DC voltage levels may change when the digital-to-analog converter (DAC) starts or stops playing an audio stream, when codec I/O ports are muted/unmuted, or when volume settings are changed. The majority of these DC voltage shifts are inherent to the codec design. System level issues, such as component leakage, can also lead to DC offsets.

Audio content

Audio content can also contribute to audible pops and clicks. Audio streams that start with a non-zero value, or are stopped at a non-zero value, produce a DC voltage shift that can be audible.

System solutions for minimizing pops and clicks

System start-up/power on

- Suggested power supply sequence:
  1) Power up digital supply
  2) Power up analog supply after a recommended 10 mS wait time. This allows the digital circuit to control the analog circuit and output stages, avoiding unknown analog states in which DC voltage shifts may be sent to the output jack
- Optimize the analog supply ramp time and VAG ramp time (using VREF_FILT capacitor value) such that the ramp is as quick as possible, without audible artifacts. (VAG ramp time is optimized in IDT codec designs; recommended VREF_FILT capacitor values are provided in IDT reference design schematics)
- All codec inputs and outputs should remain disabled until VAG has reached its maximum value, or outputs should be enabled at power-on, such that output voltages will track VAG
- Implement an external anti-pop circuit
- If external amplifiers are included in the audio subsystem, use the codec external amplifier power down (EAPD) pin to mute external amplifiers until output pin and VAG voltage levels are stable

  Note when using external amplifiers: External amplifiers often implement an independent virtual ground on the amplifier input pins. These pins are AC coupled to the codec output pins in a typical audio circuit. The system power up sequence must allow the external amplifier's virtual ground to settle before enabling the codec outputs. Consult the external amplifier manufacturer's datasheet for details regarding power-on timing virtual ground information, etc.

System shutdown/power off

- Suggested shutdown sequence:
  1) Mute all codec inputs and outputs
  2) Allow VAG to ramp down to 0 V. Note: This ramp time will be dependent on the VREF_FILT capacitor size chosen and the overall system load seen by the codec
  3) Remove analog power supply
  4) Remove digital power supply—This allows the digital circuit to remain in control of the analog circuit and output stages, avoiding unknown analog states in which DC voltage shifts may be send to the output jack
- Implement an external anti-pop circuit
- If external amplifiers are included in the audio subsystem, use the codec EAPD pin to mute external amplifiers until output pin and VAG voltage levels are stable

IDT HDA codec architecture improvements

IDT has made significant improvements to its PC audio codec architecture to decrease the occurrence of audio pop and click artifacts. These improvements and expected benefits are listed below.

- **Improvement:** Output amplifiers remain enabled when an output port is disabled and muted

  Benefits

- Reduces the change in DC offset voltage
- Output impedance of the port remains constant, simplifying the interaction between the codec output and an external amplifier
- **Improvement:** Output amplifiers enter a muted, low power state (rather than turning off) during AFG D3 power state

  Benefits

- Coupling caps remain charged; reducing pops experienced during power state transitions
- **Improvement:** Analog mutes added at mixer inputs; Output enable functionality added to the pin complexes

  Benefits

- Pops are reduced when these paths are muted or disabled before changing the DAC power state
- **Improvement:** Offsets in the analog-to-digital converter (ADC) analog signal processing path have been reduced

  Benefits

- Decreases pops heard when ADCs are muted or unmuted
- Reduces the cumulative effect of offsets becoming amplified due to gain (MIC boost gain and/or record gain) applied to the input signal
- Decreases pop at start of recording

External circuit solutions for minimizing pop and click artifacts

The improvements above can be very effective at minimizing pops and clicks. However, if the audio designer requires improved system performance, external circuits are very effective at eliminating pop and click artifacts. IDT will publish additional application notes with sample circuits that block voltage or current transients from reaching output devices, thus eliminating pops and clicks.

Glossary

ADC	Analog-to-digital converter
DAC	Digital-to-audio converter
EAPD	External amplifier power down
ESD	Electrostatic discharge
HDA	High-definition audio
VAG	Virtual analog ground

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