Circuit Refinements Ensure Quality Audio in Portable Computers

This article examines key parameters affecting headphone amp performance including: PSRR, turn-on transient suppression, and PCB grounding. Solutions. It focuses on just one application (the headphone amplifier) and uses the MAX4410 and MAX4298/MAX4299 headphone amps.

The challenge for audio designers is to make high-performance, low-noise analog circuitry co-exist with ASICs, processors, and dc-dc converters. Consider, for example, the issues affecting just one component in a typical audio-replay chain—the headphone driver.

The headphone output for a notebook PC must drive a low-impedance load (typically 32Ω; sometimes as low as 16Ω) with a signal whose amplitude ranges up to 1Vrms, while preserving the dynamic range of the source material. That may seem a simple task, but closer examination yields some harsh realities:

- The headphone output must maintain this dynamic range when powered by a single-supply voltage, which is usually derived from a dc-dc converter and shared by high-speed digital circuits.
- Given the signal amplitudes and load impedances encountered in these circuits, current peaks drawn from the supply can range up to 90mA.
- When shutting down the supply or the headphone driver, clicks or transients should be inaudible.

Power-Supply Noise

To realize a reasonable signal-to-noise ratio you must suppress the effect of power-supply noise on the headphone amplifier output, and power-supply rejection in the headphone driver is essential for that purpose. For example, the dynamic range for CD- or DVD-based material can exceed 90dB. Assuming a noise component of 100mV riding on the audio power-supply voltage, with most of its spectral content residing in the audio bandwidth, you must reduce the noise to about 30µV at the headphone output to maintain the 90dB dynamic range. Effectively, the headphone driver's PSRR must exceed 70dB at the frequency of interest.

To achieve such power-supply rejection across the audio band, a considered design approach is necessary, with particular attention to the amplifier's suppression of power-supply noise over frequency. A glance at most op-amp data sheets shows that PSRR is usually high near dc, and drops dramatically as frequency increases (usually at -20dB/decade). At 20kHz, some parts exhibit a PSRR less than 40dB.

Some dc-dc converters produce higher noise components at the upper end of the audio frequency spectrum. Though arguably less audible at those frequencies, the resulting noise at the headphone outputs is still measurable. Note that most data sheets for audio DACs (or CODECs) featuring on-board headphone drivers rarely draw the reader's attention to the PSRR specification. If one is offered, it usually appears as a single entry within the electrical characteristics, rather than a curve of PSRR vs. frequency.

Because most headphone amplifiers lack sufficient PSRR, you can add an external low-dropout (LDO) regulator to clean up the headphone amplifier's supply voltage. To achieve sufficient power-supply noise rejection at the audio outputs of a notebook PC, for instance, where +5V is still a common supply voltage for audio circuitry, certain nodes are often regulated down to 4.7V or so.

ICs such as the MAX4298/MAX4299 (ultra-high PSRR stereo drivers) increase the PSRR well above levels commonly achieved with other methods, by applying internal sub-regulation to key nodes within the device. That approach, which enables PSRR levels of over 100dB at 1KHz, eliminates the need for external regulators (Figure 1).

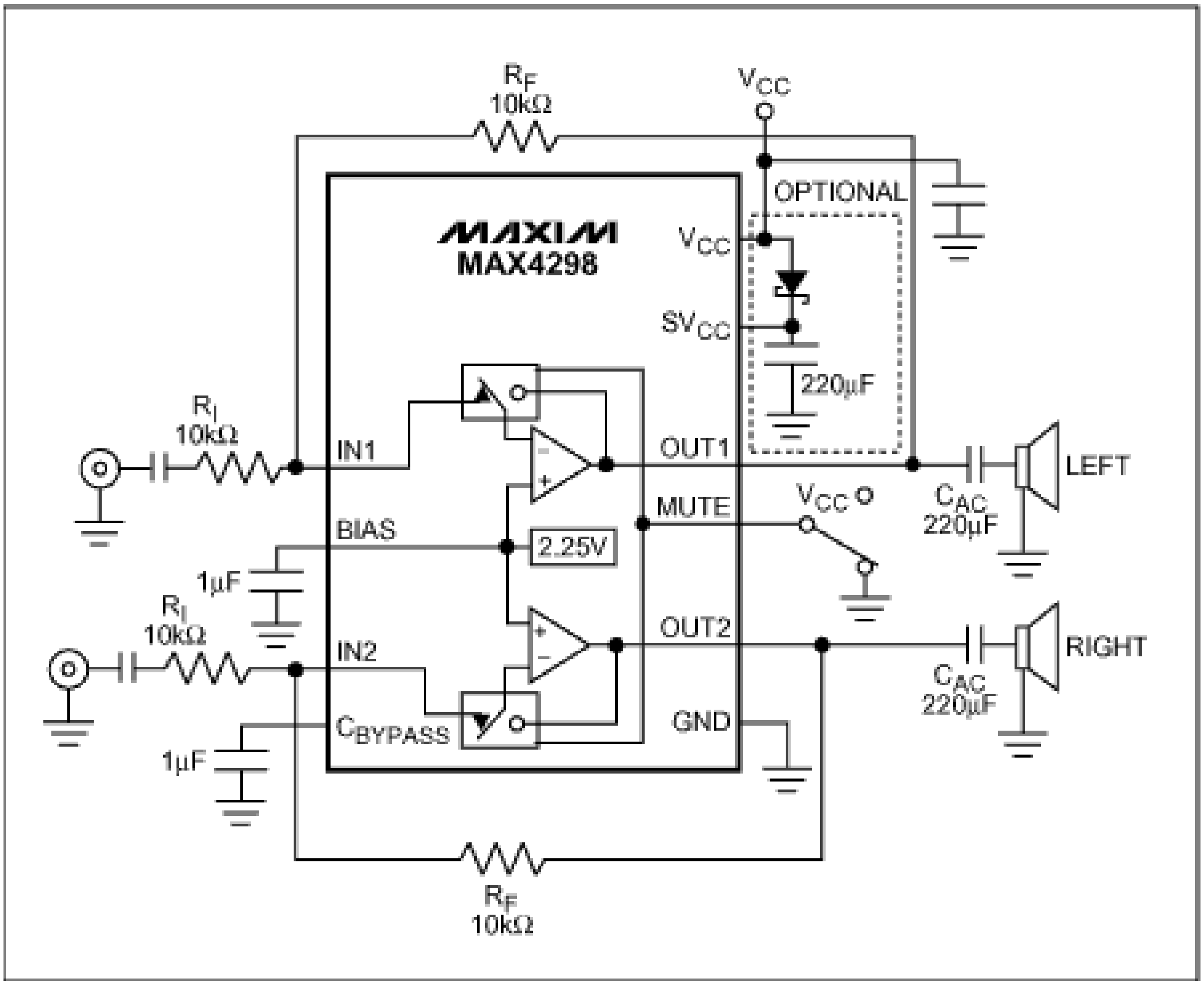

Figure 1. In this typical MAX4298 application, note that 220µF ac-coupling capacitors block the application of dc voltage to the headphones. Optional components control the magnitude of power-removal transients.

Suppression of Clicks and Pops

Click/pop suppression usually describes the ability of an IC to minimize the abrupt and often disconcerting transients that occur when the IC is muted or powered up (or down). That behavior is difficult to achieve in an output driver, for which no downstream circuitry can be muted to mask impending abnormalities. If the headphones are plugged in, then whatever is driving them inevitably makes or breaks the transient performance of the audio system.

Headphone drivers are usually powered from a single supply, with the output ac-coupled to the jack socket via a large capacitor as shown in Figure 2. That arrangement prevents dc voltage across the headphones, which can destroy the headphone drive units. During operation, the blocking capacitor has a voltage across it, since the headphone side of the capacitor is at ground potential and the amplifier output is biased approximately to mid-rail. The capacitor must be charged to its working voltage when power is applied, but the current it allows to pass in doing so must flow through the load (the headphone voice coil). What can prevent this current from producing an audible signal?

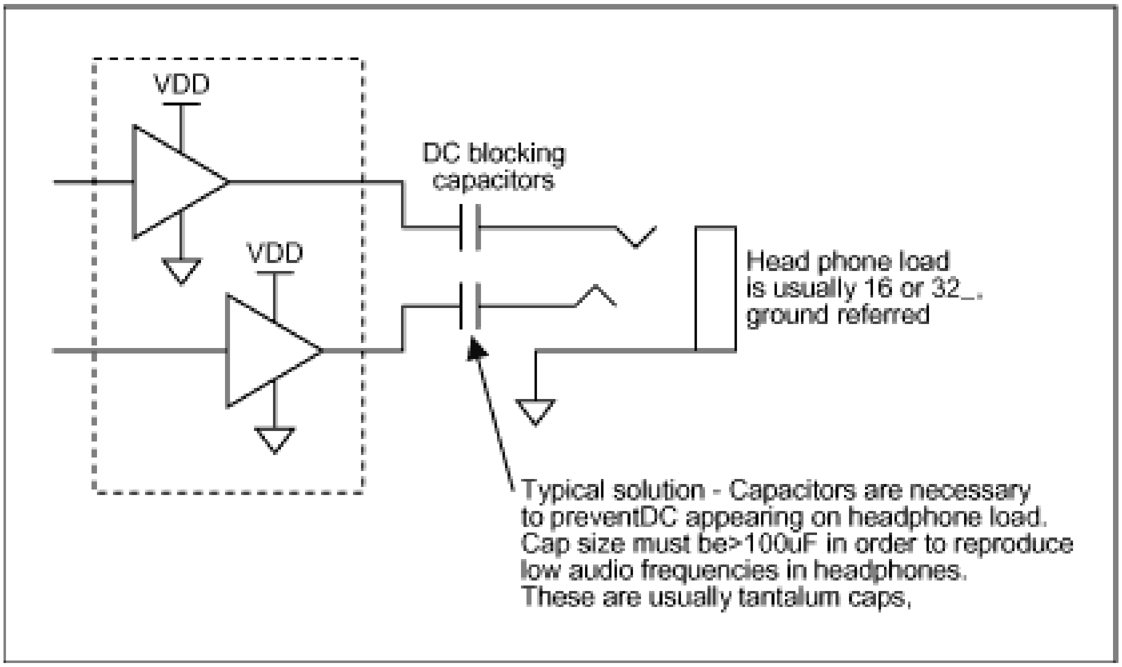

Figure 2. This circuit, the usual configuration for a headphone driver in a single-supply product, includes series capacitors that form a highpass filter with the headphone impendance (necessary to block dc from the headphones).

Some designs suppress the charging current using JFETs and discrete components around the output of the amplifier. Others provide an RC time constant to slow the turn-on transient, thereby reducing the annoyance factor by lowering the frequency content of the disturbance. At least one product employs a back-to-back exponential ramp (with S-shaped profile) to further suppress the "pops" caused by power up. Unlike the RC-exponential approach, that profile causes no abrupt changes in dv/dt.

The power-down transient is even more problematic. How can any amplifier control the output-capacitor discharge when it has no power supply? One approach provides the headphone amplifier with a standby supply consisting of a capacitor that gets charged when power is present, then supplies the amplifier with sufficient energy to shut down gracefully after the main supply is removed. An integrated application of this technique (Figure 1) produces the waveforms of Figure 3.

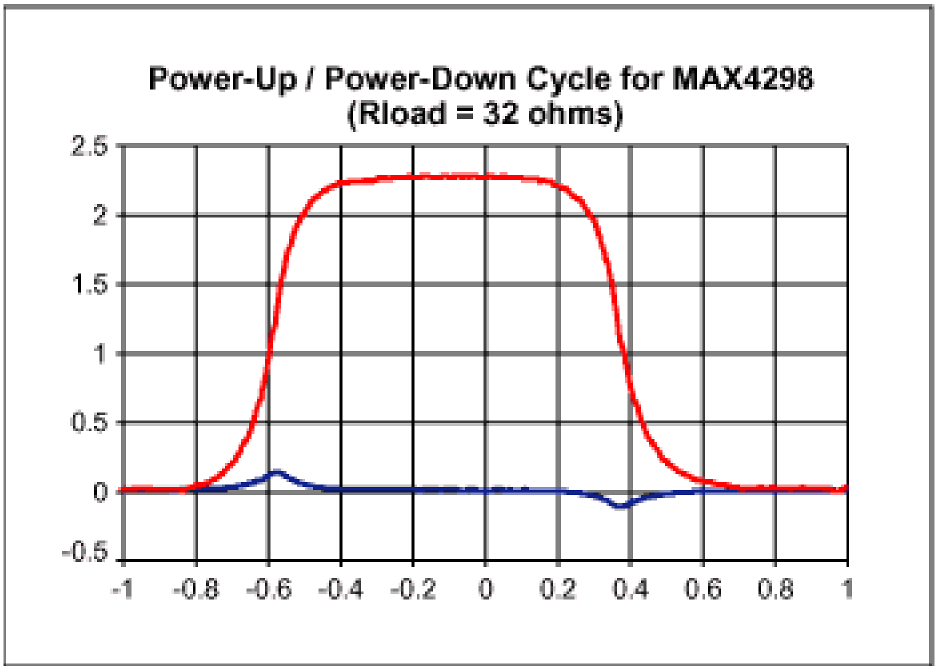

Figure 3. These waveforms illustrate the effect of applying VCC (t = -1s) and removing it (t = 0s) for the Figure 1 circuit. VCC is not shown. Note that S-shaped transitions on the MAX4298 output (upper trace) produce smooth and limited output disturbances at the load (bottom trace). The controlled output restricts turn-on transients to the low audio frequencies, to which the ear is less sensitive.

As clearly shown in Figure 3, a few additional components enable the MAX4298 to achieve a controlled, graceful power-down transient that mirrors its smooth power-up behavior. This technique involves the use of a secondary VCC pin (SVCC). An external Schottky diode charges a reservoir capacitor when VCC is present, and when power is removed the MAX4298 reacts as follows:

- Audio is muted.
- The stereo amplifiers revert to a low quiescent-current mode, deriving power from the SVCC pin.
- Output bias voltage ramps slowly to ground, using an S-shaped profile that eliminates abrupt changes in dV/dt by mirroring the power-up waveform.
- The reservoir capacitor eventually discharges, but the output voltage is at ground, so output transients are negligible when the SVCC supply eventually collapses.

A Different Approach

The solutions above represent considerable effort (and extra line items on a BOM) to satisfy an intangible feature that marketing departments may not rate very highly. An ideal approach would eliminate the output capacitors entirely, thereby negating the effect of charging or discharging through the headphone voice coils. The capacitors can be eliminated (for example) by dc-coupling the headphone drive, having a zero-volt output bias, and powering the amplifier from dual-polarity supplies.

Given that most battery-powered designs have the restriction of a single-ended supply, the designer has a couple of options. One is to use a third amplifier to bias the headphone return to (say) mid-rail, thereby creating a "pseudo-0V" output bias. Because the main stereo amplifiers are also biased at mid-rail, the dc coupling capacitors can be eliminated. Thus, the third amplifier must be capable of sinking and sourcing current from both of the main amplifiers and be robust enough to handle any ESD discharge from an incoming headphone jack (the jack sleeve is necessarily isolated from the chassis).

The other option is to generate a dedicated negative supply voltage from the positive one provided, or use a part that conveniently generates its own negative supply (Figure 4). That approach makes ESD and grounding less of an issue, and the extra voltage headroom allows the peak-to-peak output voltage to almost double–a useful capability when operating from a supply of +3V or less.

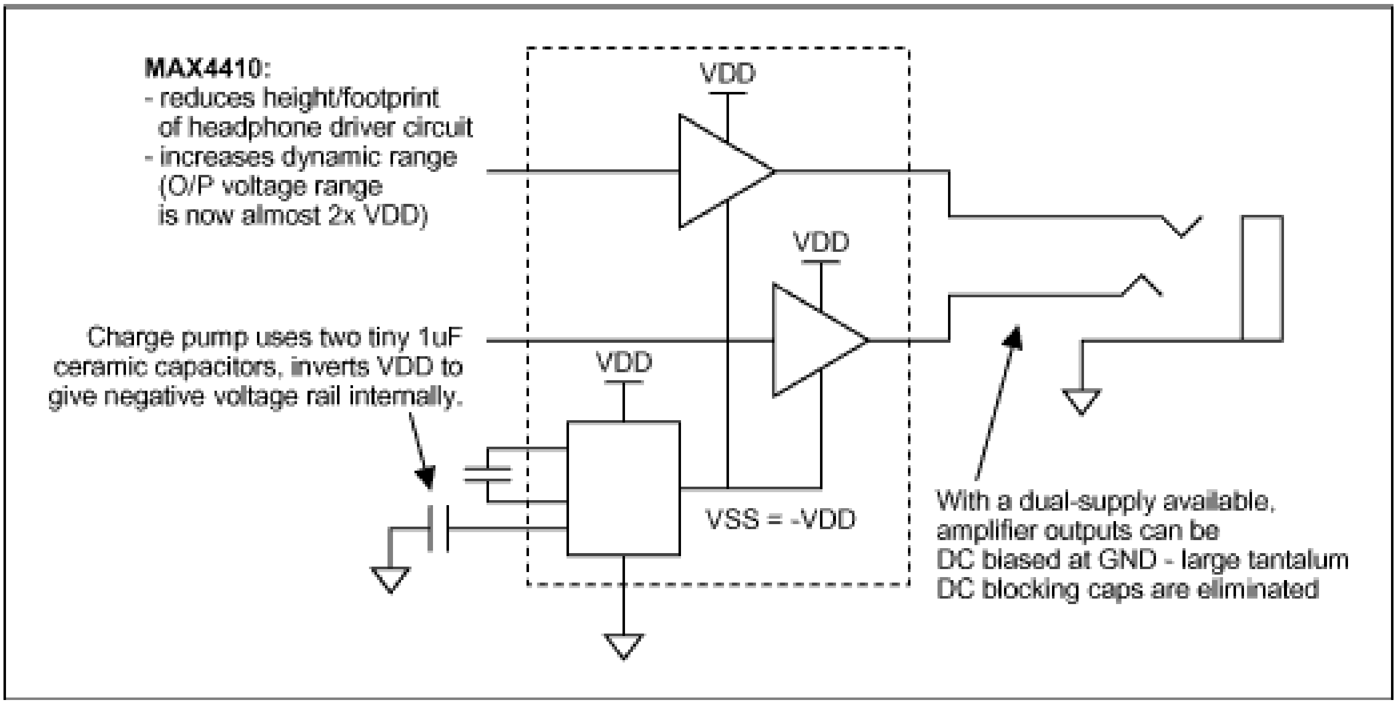

Figure 4. To allow the amlifiers to be powered from dual supplies, an on-board charge pump inverts the positive supply voltage. Series capacitors are no longer necessary, but the tiny ceramic capacitors needed for the charge pump minimize PCB area.

The MAX4410 headphone amplifier generates its own internal negative supply from the positive supply pin. Output capacitors are unnecessary because the amplifier has a dc output bias of 0V. An internal lockout circuit prevents spurious operation caused by a supply voltage that is too low or in the process of powering up or down?hence, no pops or clicks. Because the amplifier's output-voltage swing almost doubles that of a single-supply equivalent, other benefits include more signal headroom and more output power.

Further Hurdles

A working design on the bench is usually subject to many compromises before seeing product launch. ESD requirements, for instance, may call for ferrite beads or other EMC measures between the headphone driver and jack socket. Those components can have a significant impedance at audio frequencies, which can lead to crosstalk problems and a loss of output power. Careful design and Kelvin-sensing techniques, however, can recover good audio performance.

Return currents from the headphone should be considered as well. With currents pushing 100mA, the finite impedance of a ground plane or PCB track can produce significant IR drops. A similar mechanism degrades SNR when you share grounds with a dc-dc converter. Dedicated return tracks or copper fills can help in that regard.

A Digital Future?

Unless digital input headphones begin to proliferate, the circuitry driving the jack socket will necessarily remain analog. Or will it? Class D designs can maintain a digital audio path right up to the amplifier output, although filtering components are necessary to maintain efficiency and reduce EMI. PSRR and click/pop suppression can still degrade performance, so the analog hardware design engineer should remain usefully employed for at least a while longer.

More Information

MAX4298: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4299: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4410: QuickView -- Full (PDF) Data Sheet -- Free Samples