

Notebook computer upgrade path for audio power amplifiers

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Introduction

Notebook PCs are constantly changing, and their requirements for audio power amplifiers (APAs) are also changing. TI has been releasing new APAs for notebook PCs to meet the market's needs. New features added to the original innovative device, the TPA0102, have improved system functionality and performance.

The TPA0212/0312 offer internal gain settings to reduce external components; differential inputs for noise reduction; and lower supply currents. The TPA0232 adds dc volume control, while the TPA0252 has digitally controlled volume control. The newest device, the TPA2000D4, is a filterless class-D device with an integrated headphone drive. It offers higher efficiency for extended battery run-times, as well as reduced thermal dissipation.

A simplified block diagram of a notebook computer is shown in Figure 1. There are several ways to configure and interface the APA, each discussed later in this article. For more information on the audio or overall PC system, see Reference 1. Each of the devices listed in this article is suitable for use in notebook PCs, sub-notebooks, or personal digital assistants (PDAs).

External gain amplifiers (TPA0102 and TPA0202)

These devices can take the audio signal directly from the AC '97 Codec, conditioning the signal gain and enabling it to drive low-impedance speakers. Optional equalization

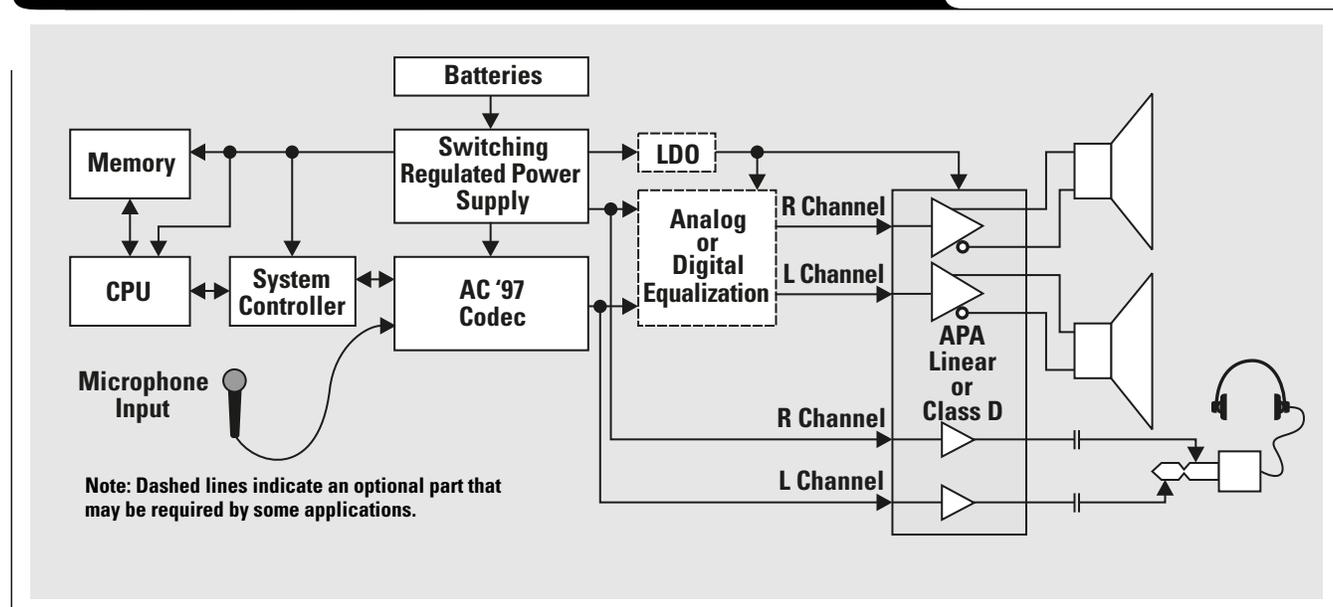
can be added between the AC '97 Codec and the APA to improve speaker fidelity by electronically flattening its response. This equalization can be done either with analog techniques using operational amplifiers, or digitally with a device like the TAS3002 digital EQ IC from TI. Figure 2 on the following page shows the TPA0202 set up in the optimal circuit configuration.

There are two sets of inputs (RLINEIN/LLINEIN and RHPIN/LHPIN) feeding an input MUX. The HP/LINE terminal controls the input MUX. This allows independent gain settings for the internal speakers and the headphones, which allows the loudness to be matched between the speakers and the headphones. Alternately, one set of inputs can be connected to the AC '97 Codec, and the other set can be connected to the analog output of the CD-ROM, allowing a mode of operation where audio CDs may be played without powering the entire notebook. Another option is to use one set of inputs for the equalized signal and the other set for the flat signal for the headphones, as they should not be equalized.

The SE/BTL terminal controls the negative output amplifier stage. In BTL mode, this amplifier is enabled, driving the speaker in BTL mode. In SE mode, the negative output amplifier is in a high-impedance state, effectively muting the internal speakers so no sound is heard from them when the headphones are in use.

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Figure 1. Simplified block diagram of the audio portion of a notebook PC



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The TPA0102 and TPA0202 use one internal stage for amplification and power output. Minimum distortion is therefore achieved by keeping the gain as low as possible, with a gain of -2 V/V (BTL) providing the highest SNR and lowest distortion in the load. The speaker gain is set by Equation 1, and the headphone gain is set by Equation 2. There are three considerations when choosing these resistors. The first is that high resistance values create a large time constant with the input ac-coupling cap, C_{IN} . When the amplifier is placed in shutdown mode, the midrail dc biasing voltage (BYPASS) drifts to ground. If Equation 4 is not satisfied, the start-up pop will increase. The second consideration is that the larger the gain of the circuit, the larger the start-up pop. The third consideration is the creation of a pole at $f = (2\pi R_{IN} C_{IN})^{-1}$. This cutoff frequency must be set to pass the desired low-end audio frequencies.

$$\text{Gain (speaker)} = -2 \left(\frac{R_{F(\text{Line})}}{R_{IN(\text{Line})}} \right) \quad (1)$$

$$\text{Gain (HP)} = - \left(\frac{R_{F(\text{HP})}}{R_{IN(\text{HP})}} \right) \quad (2)$$

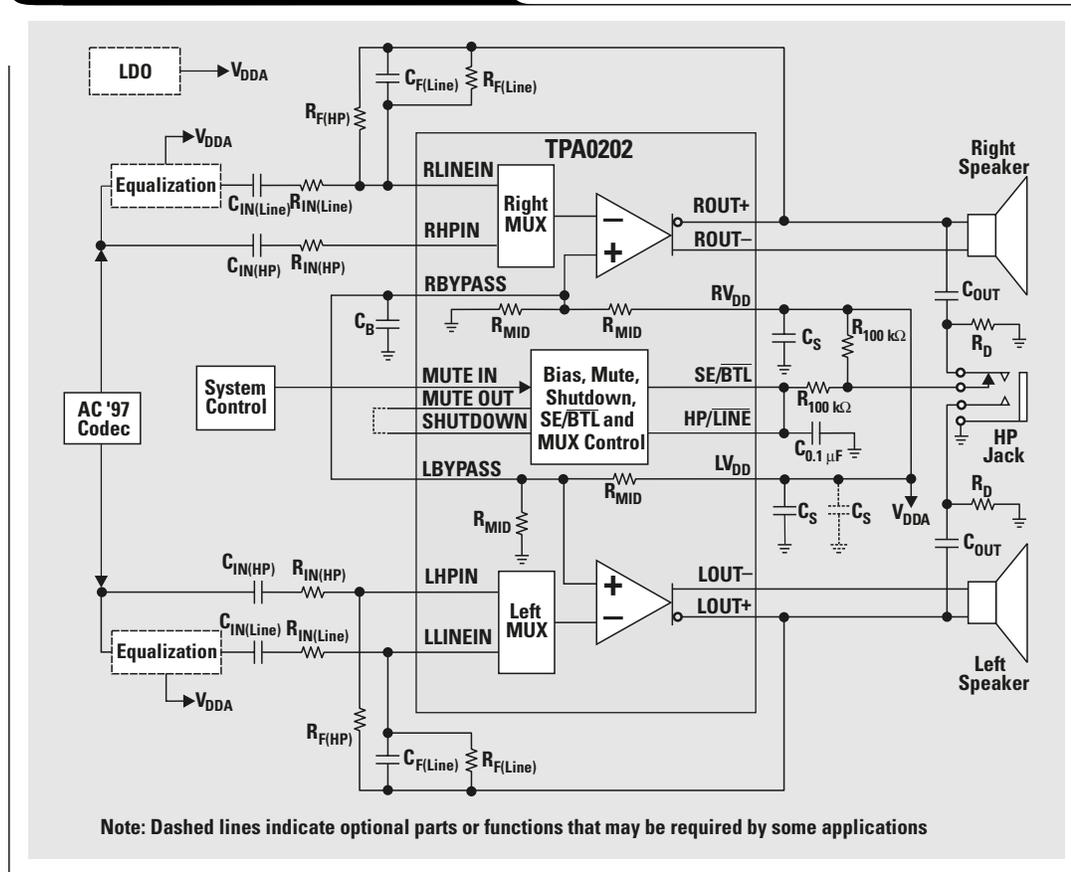
The major differences between the two amplifiers are that the TPA0102 is capable of driving 1.5 W into a 4- Ω load, while the TPA0202 can drive 2 W into a 3- Ω load and

has internal de-pop circuitry added to reduce start-up popping in the speakers. The remaining features are virtually identical, so the consideration becomes the selection of the capacitors for the circuit: ac coupling, bypass, and bulk decoupling of the power supply.

The AC '97 Codec's outputs may not be biased at the same voltage as the APA inputs; thus dc blocking capacitors are required to ac-couple the two ICs to prevent distortion in the APA. Single-ended inputs are sensitive to noise since any common-mode noise will be amplified by the APA. Careful layout reduces noise pickup. Shield the input traces from noisy digital signals, and keep the input and feedback resistors as close as possible to the APA inputs, since their high-impedance nodes are likely to pick up noise. The outputs to the single-ended load must be ac-coupled (C_{OUT}) to block any dc component from the APA, preventing a dc current from flowing through the speaker. In both cases, these capacitors combine with the series resistance (C_{IN} with R_{IN} , and C_{OUT} with the headphone resistance) to create a high-pass filter with a cutoff frequency of $(2\pi RC)^{-1}$. Ceramic capacitors are used at the inputs since R_{IN} is large. The SE output requires an electrolytic capacitor because the small resistance of the headphones requires a large capacitance to get a low cutoff frequency.

The supply decoupling capacitors (C_S) are located at the power-supply pins (RV_{DD} and LV_{DD}). The C_S capacitors decouple high-frequency signals, such as transients and spikes, from the power supply. The C_B capacitors decouple high-frequency signals that couple into the midrail biasing circuit, and help minimize the startup pop by controlling the voltage on the non-inverting terminal. Each capacitor should be a low impedance over the expected noise frequency range. The range of noise is determined by the noise sources in the system. In a notebook PC, the primary source is the hard-disk drive (HDD). The noise is caused by the rise time of the digital components as they switch on and off. According to Reference 2, the maximum frequency of this noise is calculated with Equation 3, where t_r is the rise time of the digital pulse. Periodic signals

Figure 2. TPA0202 application circuit



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floating. This is done because the RHPIN/LHPIN and RLINEIN/LINEIN inputs go to the MUX and then are applied to the inverting input of the internal amplifier, while the RIN/LIN inputs are tied to the non-inverting input. When single-ended inputs are used, the RIN/LIN pins are grounded through a capacitor of the same value as the audio signal inputs.

Table 1. Variable gain settings of the TPA0212 and TPA0312

GAIN0	GAIN1	SE/BTL	GAIN (dB)	
			TPA0212	TPA0312
0	0	0	6.0	5.6
0	1	0	15.5	9.5
1	0	0	21.5	15.1
1	1	0	27.6	21.1
X	X	1	0.0	4.1

The internal gain control is selected by the combination of two input terminals (GAIN0 and GAIN1) used in conjunction with the SE/BTL pin. Table 1 shows the gain combinations available for both the TPA0212 and TPA0312. The gain is variable for the BTL output to allow for varying efficiencies of different speaker types and varying input amplitudes from the equalization circuitry or some other signal conditioning. The gain can also be used as a limited volume control. The SE gain provides the optimal level of sound in headphones. It also minimizes start-up pop and allows a large output signal swing from the AC '97 Codec, maximizing the SNR. The input impedance varies with gain and will impact the cutoff frequency of the input filter. Assume a worst-case minimum of 10 k Ω to calculate C_{IN}.

The depop circuitry is improved and does not require any special circuits or considerations to minimize it. Choice of C_B is not directly linked to the input filter components. C_B is recommended to be between 0.47 μ F and 1 μ F for minimum THD+N.

The PC Beep allows the system processor to send a tone signal to the speaker through the PC-BEEP pin. The amplifier output is switched to BTL when the input is a pulse train or square wave signal of 1 V_{PP} or greater, with rise and fall times of less than 1 μ s and a minimum of 8 rising edges. This signal is passed to the speaker with a fixed gain of 0.3 V/V, independent of the gain setting. The PC-BEEP pin is dc-biased at midrail. When it is ac-coupled, the value of the beep coupling capacitor (C_{PCB}) should be calculated with Equation 5, where R_{PCB} = 100 k Ω is the input impedance of the PC-BEEP pin and f_{PCB} is the frequency of the control signal.

$$C_{PCB} \geq \left(\frac{1}{2\pi f_{PCB} R_{PCB}} \right) \quad (5)$$

DC or digital gain control (TPA0232 and TPA0252)

The TPA0232 provides all the features of the TPA0212 plus a dc gain (VOLUME) control. Refer to Figure 3. The GAIN0 pin becomes HP/LINE, the GAIN1 pin becomes the VOLUME, and the old HP/LINE pin becomes the CLK. A dc voltage applied directly to the VOLUME pin controls the amplifier gain. The dc level sets the gain from -40 dB to +20 dB in 31 discrete steps. The gain is 20 dB for 0 V to 0.15 V and decreases in 2-dB increments for approximately

every 120 mV. The volume is muted when the output exceeds 3.54 V. The precise values are listed in the application section of Reference 4.

The CLK pin requires a fixed 0.47-nF capacitor to ground for optimal circuit performance when the internal clock is used, which sets the clock frequency to 100 Hz. The maximum internal clock frequency is 500 Hz. The formula for calculating either C_{CLK} or f_{CLK} is shown in Equation 6.

$$f_{CLK} = \frac{4.7 \times 10^{-6}}{C_{CLK}} \quad (6)$$

An external clock can override the internal clock by removing the capacitor and applying it directly to the CLK terminal. The maximum input frequency is 10 kHz, though it should be kept at less than 200 Hz for normal operation to prevent the gain from increasing too quickly and creating pop or zipper noise in the speaker. The waveform should be a 5-V, 50%-duty-cycle square wave to operate the 4.5-V and 0.5-V trip points. In notebook PC applications, internal speakers must be driven using the single-ended (SE) mode. The device automatically switches into SE mode when the SE/BTL pin is pulled high and the gain is reduced by 6 dB from the BTL setting. See the application section of Reference 4 for more information.

The TPA0252 also provides the features of the TPA0212 plus a two-pin digital input volume control and an auxiliary volume control memory pin (V_{AUX}). The digital input volume control has two active low-input control pins (UP/DOWN). The default volume is initially set at -10 dB and is increased or decreased in 31 discrete, 2-dB steps over a range from -40 dB to +20 dB in BTL mode. When in SE mode, the gain is 6 dB lower than the BTL gain for the same input. An active low voltage on the UP pin causes the gain to increase, and on the DOWN pin causes the gain to decrease. When the UP/DOWN pin is held low, the gain will increase/decrease by 2 dB per clock cycle.

The volume control works in conjunction with the CLK, which functions as described for the TPA0232. The V_{AUX} terminal is used to maintain power to the volume control memory. The device will remember the last volume setting when a voltage of greater than 3 V is applied to the V_{AUX} terminal, even when the device is powered down or in shutdown mode. When V_{AUX} is pulled low, the device resets to a volume setting of -10 dB in BTL mode. See the application section of Reference 5 for more information.

Class-D high-efficiency APA (TPA2000D4)

The TPA2000D4 is a class-D APA capable of filterless operation and offers many of the features of the TPA0212, with some additional benefits:

- Greater efficiency: 70% filterless vs. 25% class-AB APA, providing these benefits:
 - longer battery life
 - lower supply-current demand from LDO
 - less heat due to less internal power dissipation
- Multiple internal BTL gains
- Fully differential inputs with SE HP inputs
- Lower shutdown current: 1 μ A vs. 150 μ A

The efficiency of the TPA2000D4 is its greatest advantage, offering longer battery life, lower supply current, and less

heat. These are important factors as the notebook computer market struggles to attain longer operation for the system. The new modulation scheme and filterless operation allow great reductions in size and cost as well as in the quiescent current and supply current drawn while playing audio.

The TPA2000D2, which is a similar part but without the headphone amplifier, passed FCC- and CE-radiated emissions with no shielding and a speaker wire 8" long or less. This is ideal for the notebook computer, where trace/wire length is short. For longer leads, the device can be used with a ferrite bead or complete LC filter. See the application section of Reference 6 for more details.

The differential inputs can be configured for SE operation by ac grounding the RINP and LINP pins with the same capacitance used on the audio inputs. The same considerations apply as for the TPA0212 amplifier already discussed, with the exception of the input capacitor, which must be at least 10 times smaller than the midrail capacitor on the bypass pin, C_B , to reduce the startup popping. The values that change are the input impedance, which is a minimum of 20 k Ω , and the actual gain levels. The gain is set with 2 input terminals similar to those for the TPA0212. The midrail bypass capacitor, C_B , also performs the same function and should be 1 μ F. The power-supply pin decoupling now requires two capacitors, one high- and one low-frequency, to filter out the noise of the system. The same rules apply as before for the placement and type of capacitor chosen. It is critical that the high-frequency decoupling capacitor(s) be placed as close as possible to the IC pins.

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References

1. Intel Corporation and Microsoft Corporation, "PC 2001 System Design Guide" (November 2, 2000).
2. Henry W. Ott, Noise Reduction Techniques in Electronic Systems (John Wiley & Sons, 1976).

For TI information related to this article, you can download an Acrobat Reader file at www-s.ti.com/sc/techlit/litnumber and replace "litnumber" with the **TI Lit. #** for the following document.

Document Title	TI Lit. #
3. "TPA0213 2-W Mono Audio Power Amplifier with Headphone Drive," Data Sheet	slos276
4. "TPA0232 Stereo 2-W Audio Power Amplifier with DC Volume Control and MUX Control," Data Sheet	slos286
5. "TPA0252 Stereo 2-W Audio Power Amplifier with Digital Volume Control," Data Sheet	slos288
6. "TPA2000D4 Stereo 2-W Class-D Audio Power Amplifier with Stereo Headphone Amplifier," Data Sheet	slos337
7. "TPA0212 Stereo 2-W Audio Power Amplifier with Four Selectable Gain Settings and MUX Control," Data Sheet	slos284
8. "TPA0312 2-W Stereo Audio Power Amplifier with Four Selectable Gain Settings and MUX Control," Data Sheet	slos335

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Replace *device* with tpa0102, tpa0202, tpa0212, tpa0232, tpa0252, tpa0312, tpa2000D2, or tpa2000D4

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