National Semiconductor

PRELIMINARY
August 1996

LM1876 *Overture*™ Audio Power Amplifier Series
Dual 20W Audio Power Amplifier with Mute and Standby Modes

General Description

The LM1876 is a stereo audio amplifier capable of delivering typically 20W per channel of continuous average output power into a 4Ω or 8Ω load with less than 0.1% (THD + N).

Each amplifier has an independent smooth transition fade-in/out mute and a power conserving standby mode which can be controlled by external logic.

The performance of the LM1876, utilizing its Self Peak Instantaneous Temperature (°Ke) **(SPiKe™)** Protection Circuitry, places it in a class above discrete and hybrid amplifiers by providing an inherently, dynamically protected Safe Operating Area (SOA). **SPiKe** Protection means that these parts are safeguarded at the output against overvoltage, undervoltage, overloads, including thermal runaway and instantaneous temperature peaks.

Key Specifications

- THD+N at 1 kHz at 2 x 15W continuous average output power into 4Ω or 8Ω — 0.1% (max)
- THD+N at 1 kHz at continuous average output power of 2 x 20W into 8Ω — 0.009% (typ)
- Standby current — 4.2 mA (typ)

Features

- SPiKe Protection
- Minimal amount of external components necessary
- Quiet fade-in/out mute mode
- Standby-mode
- Isolated 15-lead TO-220 package

Applications

- High-end stereo TVs
- Component stereo
- Compact stereo

Typical Application

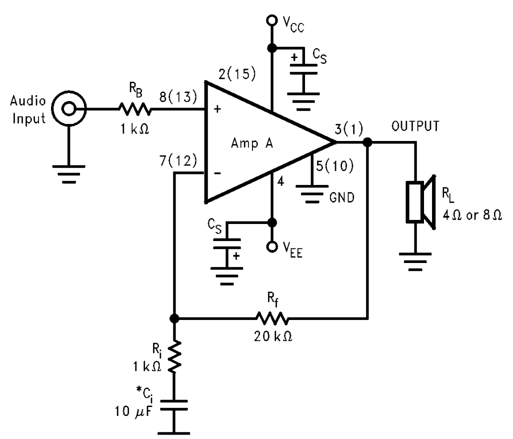


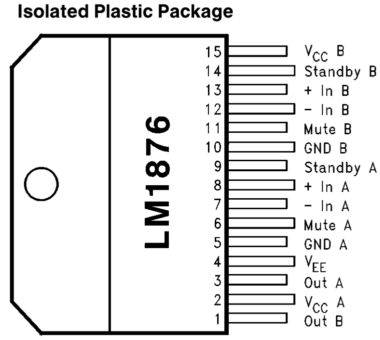
FIGURE 1. Typical Audio Amplifier Application Circuit

Note: Numbers in parentheses represent pinout for amplifier B.

*Optional component dependent upon specific design requirements.

Connection Diagram

Isolated Plastic Package



Top View

Order Number LM1876TF
See NS Package Number TF15B

Absolute Maximum Ratings (Notes 1 and 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage $\|V_{CC}\| + \|V_{EE}\|$ (No Input)	64V
Supply Voltage $\|V_{CC}\| + \|V_{EE}\|$ (with Input)	64V
Common Mode Input Voltage	(V_{CC} or V_{EE}) and $\|V_{CC}\| + \|V_{EE}\| \leq 54V$
Differential Input Voltage	54V
Output Current	Internally Limited
Power Dissipation (Note 3)	62.5W
ESD Susceptability (Note 4)	2000V
Junction Temperature (Note 5)	150°C
Thermal Resistance	
θ_{JC} (Note 11)	2°C/W
θ_{JA}	43°C/W
Soldering Information	
TF Package (10 sec.)	260°C
Storage Temperature	−40°C to +150°C

Operating Ratings (Notes 1 and 2)

Temperature Range	
$T_{MIN} \leq T_A \leq T_{MAX}$	$-20°C \leq T_A \leq +85°C$
Supply Voltage $\|V_{CC}\| + \|V_{EE}\|$	20V to 64V

Note: Operation is guaranteed up to 64V, however, distortion may be introduced from **SPiKe** Protection Circuitry if proper thermal considerations are not taken into account. Refer to the **Application Information** section for a complete explanation.

Electrical Characteristics (Notes 1 and 2) The following specifications apply for $V_{CC} = +22V$, $V_{EE} = -22V$ with $R_L = 8\Omega$ unless otherwise specified. Limits apply for $T_A = 25°C$.

Symbol	Parameter	Conditions	LM1876		Units (Limits)
			Typical (Note 6)	Limit (Note 7)	
$\|V_{CC}\| + \|V_{EE}\|$	Power Supply Voltage (Note 8)	$GND - V_{EE} \geq 9V$		20 64	V (min) V (max)
$**P_O$	Output Power (Continuous Average)	THD + N = 0.1% (max), f = 1 kHz $\|V_{CC}\| = \|V_{EE}\| = 22V$, $R_L = 8\Omega$ $\|V_{CC}\| = \|V_{EE}\| = 20V$, $R_L = 4\Omega$ (Note 10)	 20 22	 15 15	 W/ch (min) W/ch (min)
THD + N	Total Harmonic Distortion Plus Noise	15 W/ch, $R_L = 8\Omega$ 15 W/ch, $R_L = 4\Omega$, $\|V_{CC}\| = \|V_{EE}\| = 20V$ 20 Hz ≤ f ≤ 20 kHz, A_V = 26 dB	0.08 0.1		% %
X_{talk}	Channel Separation	f = 1 kHz, V_O = 10.9 Vrms	80		dB
**SR	Slew Rate	V_{IN} = 1.414 Vrms, t_{rise} = 2 ns	18	12	V/µs (min)
$*I_{total}$	Total Quiescent Power Supply Current	Both Amplifiers V_{CM} = 0V, V_O = 0V, I_O = 0 mA Standby: Off Standby: On	 50 4.2	 80 6	 mA (max) mA (max)
$*V_{OS}$	Input Offset Voltage	V_{CM} = 0V, I_O = 0 mA	2.0	15	mV (max)
I_B	Input Bias Current	V_{CM} = 0V, I_O = 0 mA	0.2	0.5	µA (max)
I_{OS}	Input Offset Current	V_{CM} = 0V, I_O = 0 mA	0.002	0.2	µA (max)
I_O	Output Current Limit	$\|V_{CC}\| = \|V_{EE}\| = 10V$, t_{ON} = 10 ms, V_O = 0V	3.5	2.9	A (min)
$*V_{OD}$	Output Dropout Voltage (Note 9)	$\|V_{CC}-V_O\|$, V_{CC} = 20V, I_O = +100 mA $\|V_O-V_{EE}\|$, V_{EE} = −20V, I_O = −100 mA	1.8 2.5	2.3 3.2	V (max) V (max)

*DC Electrical Test; Refer to Test Circuit #1.

**AC Electrical Test; Refer to Test Circuit #2.

Electrical Characteristics (Notes 1 and 2) The following specifications apply for V_{CC} = +22V, V_{EE} = −22V with R_L = 8Ω unless otherwise specified. Limits apply for T_A = 25°C (Continued)

Symbol	Parameter	Conditions	LM1876		Units (Limits)
			Typical (Note 6)	Limit (Note 7)	
*PSRR	Power Supply Rejection Ratio	V_{CC} = 25V to 10V, V_{EE} = −25V, V_{CM} = 0V, I_O = 0 mA	115	85	dB (min)
		V_{CC} = 25V, V_{EE} = −25V to −10V V_{CM} = 0V, I_O = 0 mA	110	85	dB (min)
*CMRR	Common Mode Rejection Ratio	V_{CC} = 35V to 10V, V_{EE} = −10V to −35V, V_{CM} = 10V to −10V, I_O = 0 mA	110	80	dB (min)
*A_{VOL}	Open Loop Voltage Gain	R_L = 2 kΩ, Δ V_O = 20 V	110	90	dB (min)
GBWP	Gain Bandwidth Product	f_O = 100 kHz, V_{IN} = 50 mVrms	7.5	5	MHz (min)
**e_{IN}	Input Noise	IHF—A Weighting Filter R_{IN} = 600Ω (Input Referred)	2.0	8	μV (max)
SNR	Signal-to-Noise Ratio	P_O = 1W, A—Weighted, Measured at 1 kHz, R_S = 25Ω	98		dB
		P_O = 15W, A—Weighted Measured at 1 kHz, R_S = 25Ω	108		dB
A_M	Mute Attenuation	Pin 6,11 at 2.5V	115	80	dB (min)
Standby Pin					
V_{IL}	Standby Low Input Voltage	Not in Standby Mode		0.8	V (max)
V_{IH}	Standby High Input Voltage	In Standby Mode	2.0	2.5	V (min)
Mute pin					
V_{IL}	Mute Low Input Voltage	Outputs Not Muted		0.8	V (max)
V_{IH}	Mute High Input Voltage	Outputs Muted	2.0	2.5	V (min)

*DC Electrical Test; Refer to Test Circuit #1.

**AC Electrical Test; Refer to Test Circuit #2.

Note 1: All voltages are measured with respect to the GND pins (5, 10), unless otherwise specified.

Note 2: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. Electrical Characteristics state DC and AC electrical specifications under particular test conditions which guarantee specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not guaranteed for parameters where no limit is given, however, the typical value is a good indication of device performance.

Note 3: For operating at case temperatures above 25°C, the device must be derated based on a 150°C maximum junction temperature and a thermal resistance of θ_{JC} = 2°C/W (junction to case). Refer to the section Determining the Correct Heat Sink in the **Application Information** section.

Note 4: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 5: The operating junction temperature maximum is 150°C, however, the instantaneous Safe Operating Area temperature is 250°C.

Note 6: Typicals are measured at 25°C and represent the parametric norm.

Note 7: Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

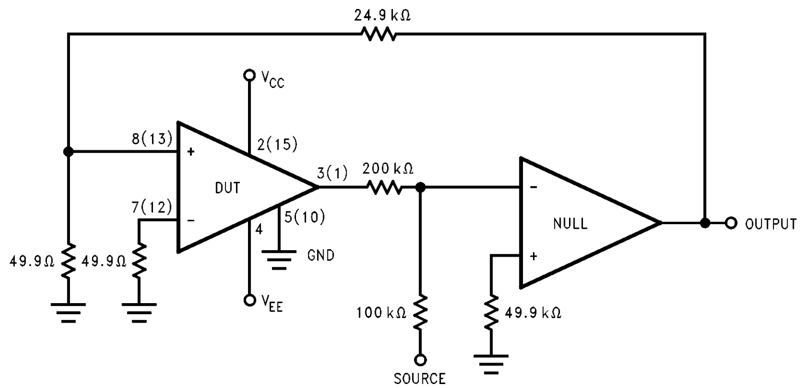
Note 8: V_{EE} must have at least −9V at its pin with reference to ground in order for the under-voltage protection circuitry to be disabled. In addition, the voltage differential between V_{CC} and V_{EE} must be greater than 14V.

Note 9: The output dropout voltage, V_{OD}, is the supply voltage minus the clipping voltage. Refer to the Clipping Voltage vs. Supply Voltage graph in the **Typical Performance Characteristics** section.

Note 10: For a 4Ω load, and with ±20V supplies, the LM1876 can deliver typically 22W of continuous average output power with less than 0.1% (THD + N). With supplies above ±20V, the LM1876 cannot deliver more than 22W into a 4Ω due to current limiting of the output transistors. Thus, increasing the power supply above ±20V will only increase the internal power dissipation, not the possible output power. Increased power dissipation will require a larger heat sink as explained in the **Application Information** section.

Note 11: Preliminary engineering evaluation of θ_{JC} for the TF package has been assessed as 2°C/W. This is a preliminary engineering number and represents the data to this point. Please contact your local National Semiconductor sales representative for more information.

Test Circuit # 1 *(DC Electrical Test Circuit)



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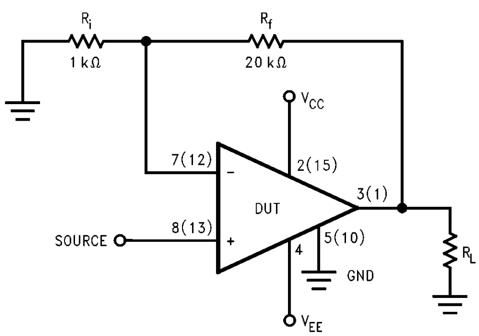
Test Circuit # 2 **(AC Electrical Test Circuit)



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Bridged Amplifier Application Circuit

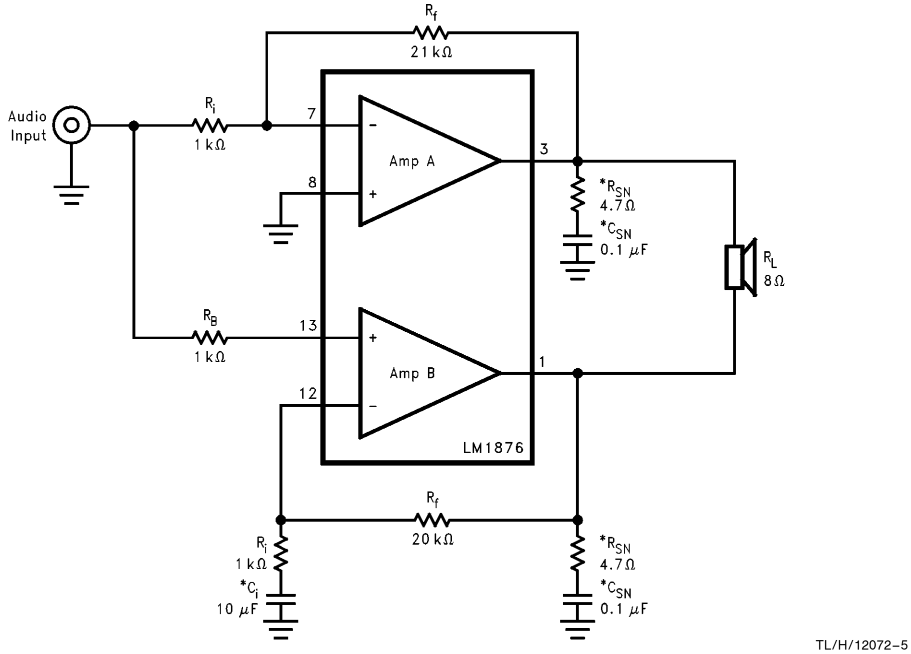


FIGURE 2. Bridged Amplifier Application Circuit

Single Supply Application Circuit

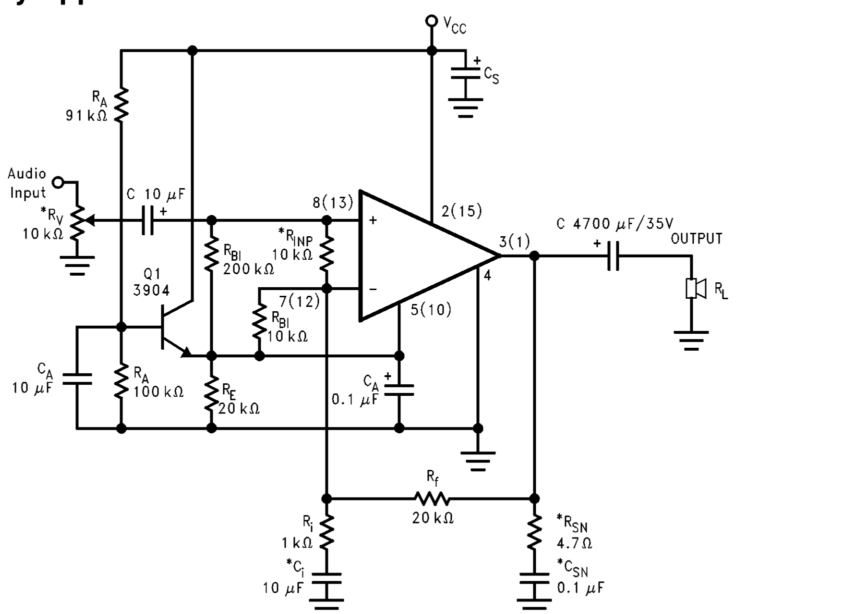


FIGURE 3. Single Supply Amplifier Application Circuit

*Optional components dependent upon specific design requirements.

Auxiliary Amplifier Application Circuit

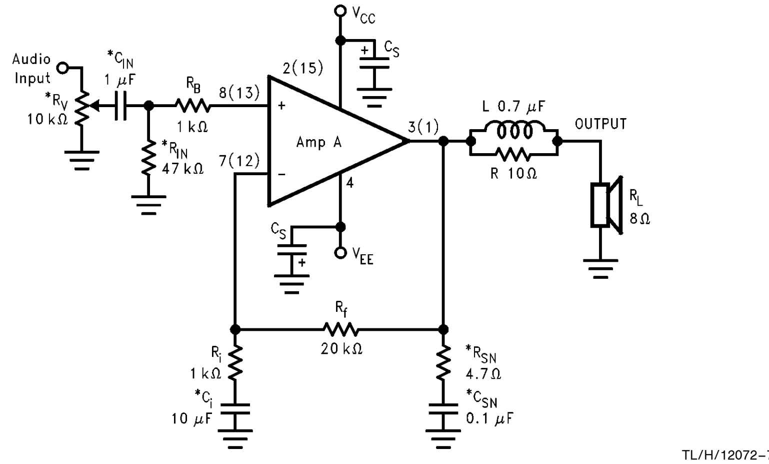
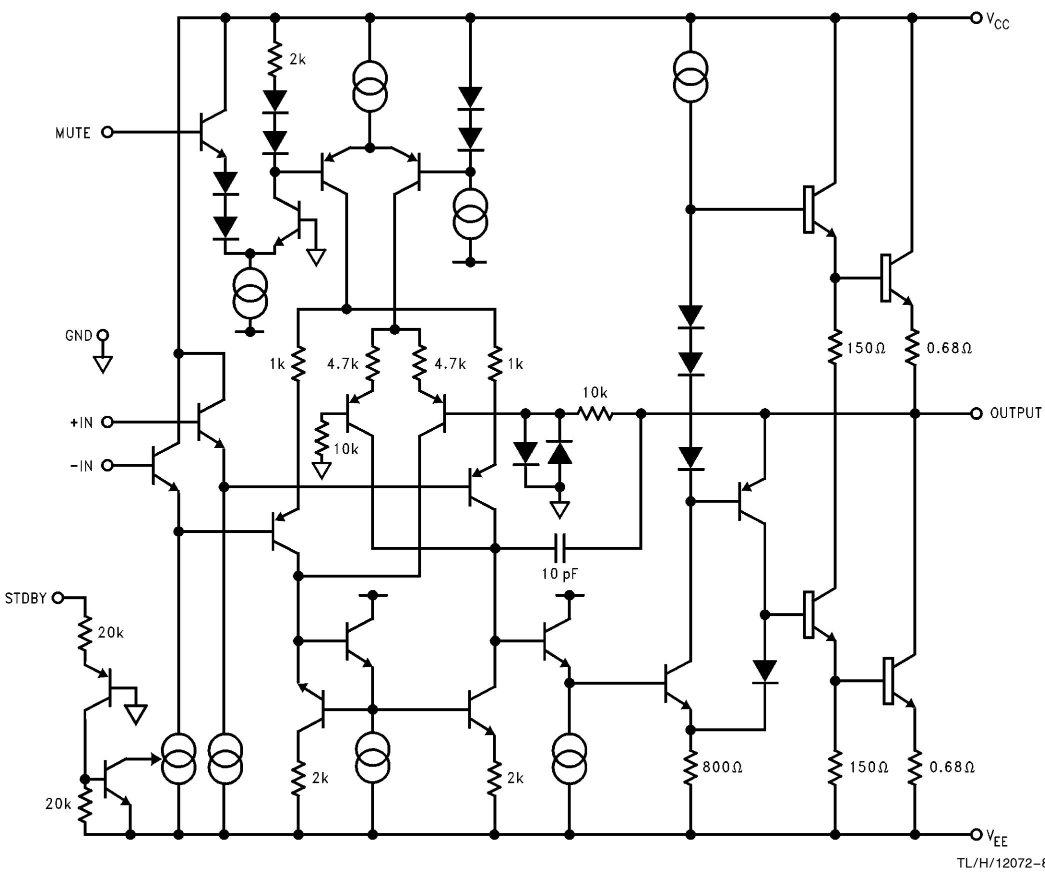


FIGURE 4. Special Audio Amplifier Application Circuit

Equivalent Schematic (excluding active protection circuitry)

LM1876 (per Amp)



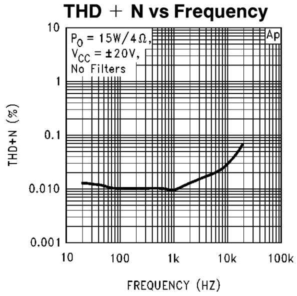
External Components Description

Components		Functional Description
1	R_B	Prevents currents from entering the amplifier's non-inverting input which may be passed through to the load upon power down of the system due to the low input impedance of the circuitry when the undervoltage circuitry is off. This phenomenon occurs when the supply voltages are below 1.5V.
2	R_i	Inverting input resistance to provide AC gain in conjunction with R_f.
3	R_f	Feedback resistance to provide AC gain in conjunction with R_i.
4	$*C_i$	Feedback capacitor which ensures unity gain at DC. Also creates a highpass filter with R_i at $f_C = 1/(2\pi R_i C_i)$.
5	C_S	Provides power supply filtering and bypassing. Refer to the Supply Bypassing application section for proper placement and selection of bypass capacitors.
6	$*R_V$	Acts as a volume control by setting the input voltage level.
7	$*R_{IN}$	Sets the amplifier's input terminals DC bias point when C_{IN} is present in the circuit. Also works with C_{IN} to create a highpass filter at $f_C = 1/(2\pi R_{IN} C_{IN})$. Refer to *Figure 4*.
8	$*C_{IN}$	Input capacitor which blocks the input signal's DC offsets from being passed onto the amplifier's inputs.
9	$*R_{SN}$	Works with C_{SN} to stabilize the output stage by creating a pole that reduces high frequency instabilities.
10	$*C_{SN}$	Works with R_{SN} to stabilize the output stage by creating a pole that reduces high frequency instabilities. The pole is set at $f_C = 1/(2\pi R_{SN} C_{SN})$. Refer to *Figure 4*.
11 12	*L *R	Provides high impedance at high frequencies so that R may decouple a highly capacitive load and reduce the Q of the series resonant circuit. Also provides a low impedance at low frequencies to short out R and pass audio signals to the load. Refer to *Figure 4*.
13	R_A	Provides DC voltage biasing for the transistor Q1 in single supply operation.
14	C_A	Provides bias filtering for single supply operation.
15	$*R_{INP}$	Limits the voltage difference between the amplifier's inputs for single supply operation. Refer to the **Clicks and Pops** application section for a more detailed explanation of the function of R_{INP}.
16	R_{BI}	Provides input bias current for single supply operation. Refer to the **Clicks and Pops** application section for a more detailed explanation of the function of R_{BI}.
17	R_E	Establishes a fixed DC current for the transistor Q1 in single supply operation. This resistor stabilizes the half-supply point along with C_A.

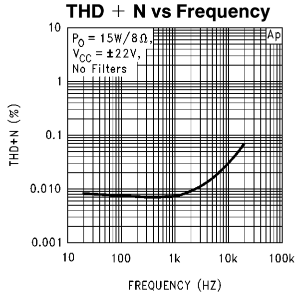
*Optional components dependent upon specific design requirements.

Typical Performance Characteristics

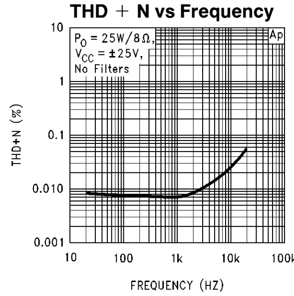
THD + N vs Frequency



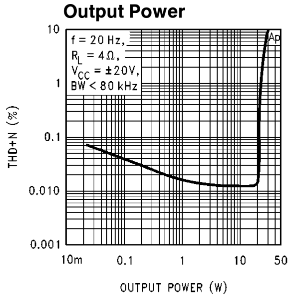
THD + N vs Frequency



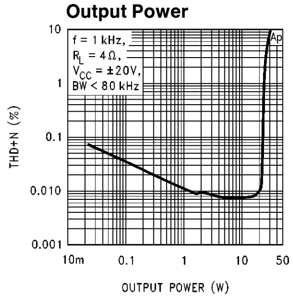
THD + N vs Frequency



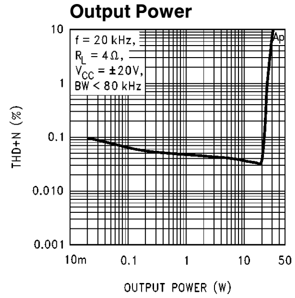
THD + N vs Output Power



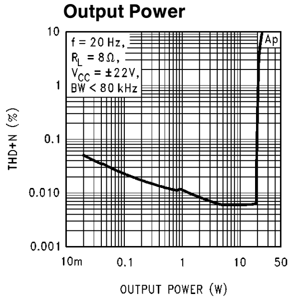
THD + N vs Output Power



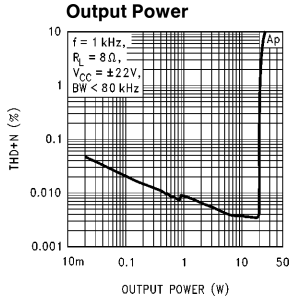
THD + N vs Output Power



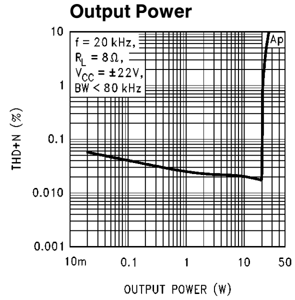
THD + N vs Output Power



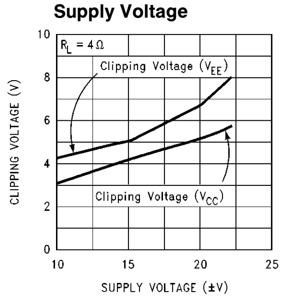
THD + N vs Output Power



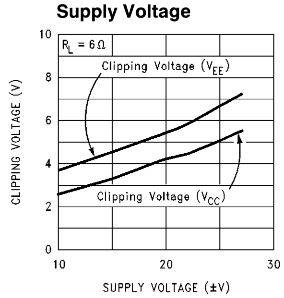
THD + N vs Output Power



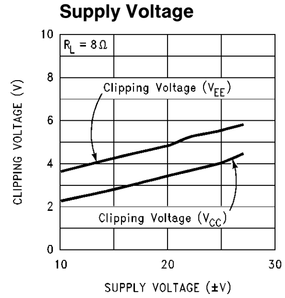
Clipping Voltage vs Supply Voltage



Clipping Voltage vs Supply Voltage



Clipping Voltage vs Supply Voltage



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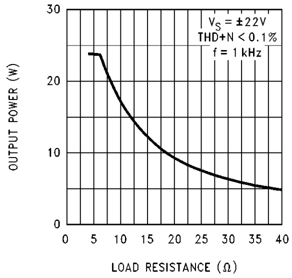
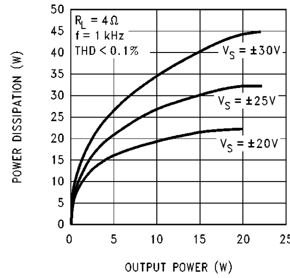
Typical Performance Characteristics (Continued)

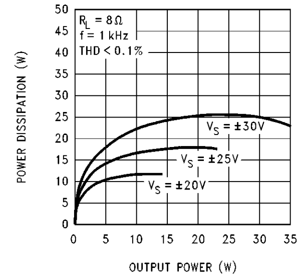
Output Power vs Load Resistance



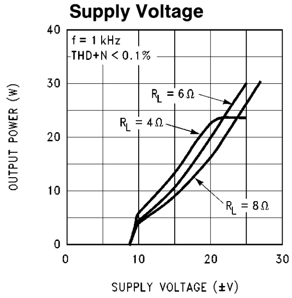
Power Dissipation vs Output Power



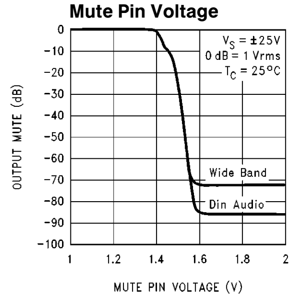
Power Dissipation vs Output Power



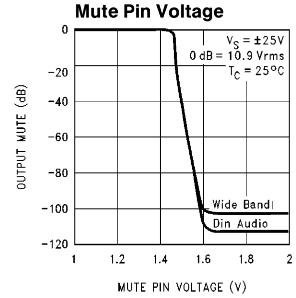
Output Power vs Supply Voltage



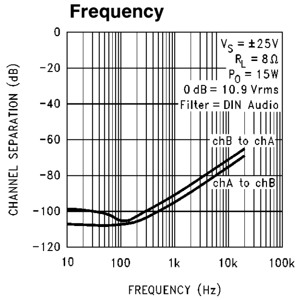
Output Mute vs Mute Pin Voltage



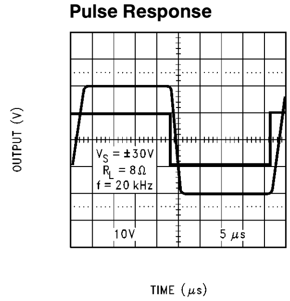
Output Mute vs Mute Pin Voltage



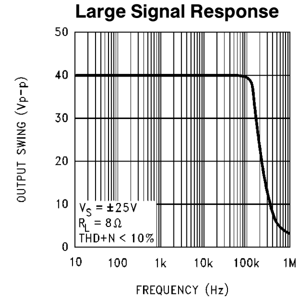
Channel Separation vs Frequency



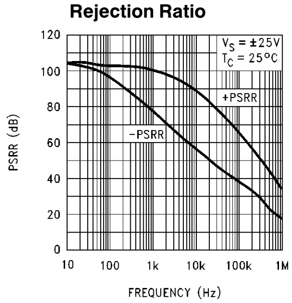
Pulse Response



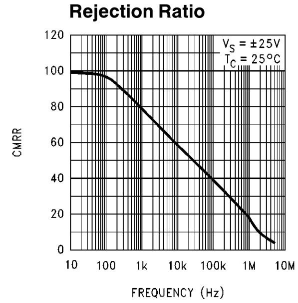
Large Signal Response



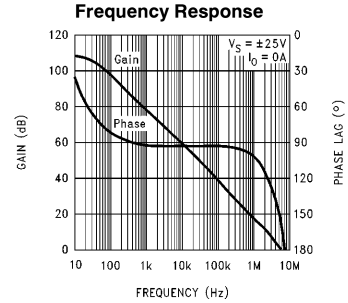
Power Supply Rejection Ratio



Common-Mode Rejection Ratio



Open Loop Frequency Response



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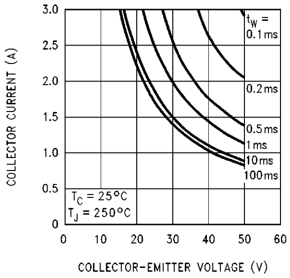
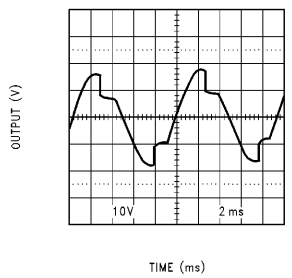
Typical Performance Characteristics (Continued)

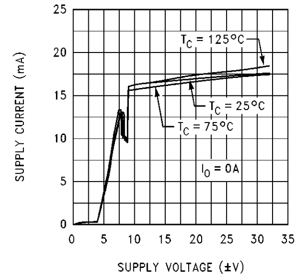
Safe Area



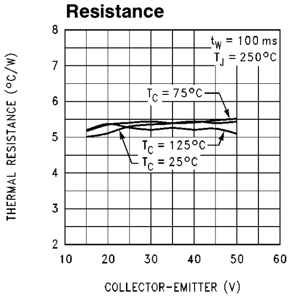
SPiKe Protection Response



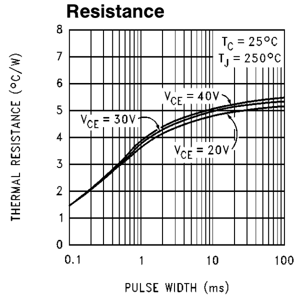
Supply Current vs Supply Voltage



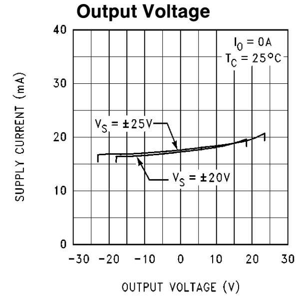
Pulse Thermal Resistance



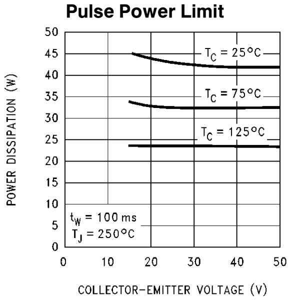
Pulse Thermal Resistance



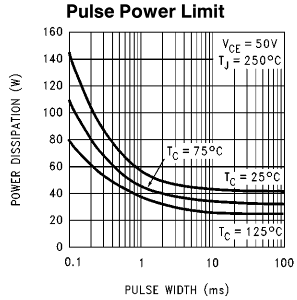
Supply Current vs Output Voltage



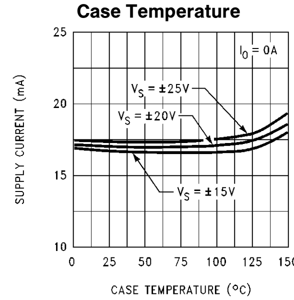
Pulse Power Limit



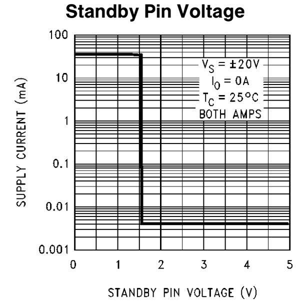
Pulse Power Limit



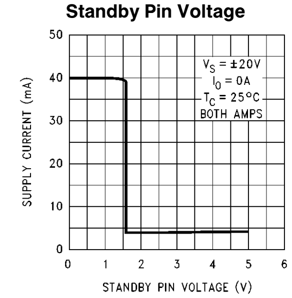
Supply Current vs Case Temperature



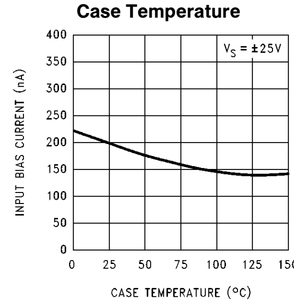
Supply Current (I_{CC}) vs Standby Pin Voltage



Supply Current (I_{EE}) vs Standby Pin Voltage



Input Bias Current vs Case Temperature



TL/H/12072–9

Application Information

MUTE MODE

By placing a logic-high voltage on the mute pins, the signal going into the amplifiers will be muted. If the mute pins are left floating or connected to a logic-low voltage, the amplifiers will be in a non-muted state. There are two mute pins, one for each amplifier, so that one channel can be muted without muting the other if the application requires such a configuration. Refer to the **Typical Performance Characteristics** section for curves concerning Mute Attenuation vs Mute Pin Voltage.

STANDBY MODE

The standby mode of the LM1876 allows the user to drastically reduce power consumption when the amplifiers are idle. By placing a logic-high voltage on the standby pins, the amplifiers will go into Standby Mode. In this mode, the current drawn from the V_{CC} supply is typically less than 10 μA total for both amplifiers. The current drawn from the V_{EE} supply is typically 4.2 mA. Clearly, there is a significant reduction in idle power consumption when using the standby mode. There are two Standby pins, so that one channel can be put in standby mode without putting the other amplifier in standby if the application requires such flexibility. Refer to the **Typical Performance Characteristics** section for curves showing Supply Current vs. Standby Pin Voltage for both supplies.

UNDER-VOLTAGE PROTECTION

Upon system power-up, the under-voltage protection circuitry allows the power supplies and their corresponding capacitors to come up close to their full values before turning on the LM1876 such that no DC output spikes occur. Upon turn-off, the output of the LM1876 is brought to ground before the power supplies such that no transients occur at power-down.

OVER-VOLTAGE PROTECTION

The LM1876 contains over-voltage protection circuitry that limits the output current to approximately 3.5 Apk while also providing voltage clamping, though not through internal clamping diodes. The clamping effect is quite the same, however, the output transistors are designed to work alternately by sinking large current spikes.

SPiKe PROTECTION

The LM1876 is protected from instantaneous peak-temperature stressing of the power transistor array. The Safe Operating graph in the **Typical Performance Characteristics** section shows the area of device operation where **SPiKe** Protection Circuitry is not enabled. The waveform to the right of the SOA graph exemplifies how the dynamic protection will cause waveform distortion when enabled.

THERMAL PROTECTION

The LM1876 has a sophisticated thermal protection scheme to prevent long-term thermal stress of the device. When the temperature on the die reaches 165°C, the LM1876 shuts down. It starts operating again when the die temperature drops to about 155°C, but if the temperature again begins to rise, shutdown will occur again at 165°C. Therefore, the device is allowed to heat up to a relatively high temperature if the fault condition is temporary, but a sustained fault will cause the device to cycle in a Schmitt Trigger fashion between the thermal shutdown temperature limits of 165°C and 155°C. This greatly reduces the stress imposed on the IC by thermal cycling, which in turn improves its reliability under sustained fault conditions.

Since the die temperature is directly dependent upon the heat sink used, the heat sink should be chosen such that thermal shutdown will not be reached during normal operation. Using the best heat sink possible within the cost and space constraints of the system will improve the long-term reliability of any power semiconductor device, as discussed in the **Determining the Correct Heat Sink** Section.

DETERMINING MAXIMUM POWER DISSIPATION

Power dissipation within the integrated circuit package is a very important parameter requiring a thorough understanding if optimum power output is to be obtained. An incorrect maximum power dissipation calculation may result in inadequate heat sinking causing thermal shutdown and thus limiting the output power.

Equation (1) exemplifies the theoretical maximum power dissipation point of each amplifier where V_{CC} is the total supply voltage.

$$P_{DMAX} = V_{CC}^2/2\pi^2 R_L \quad (1)$$

Thus by knowing the total supply voltage and rated output load, the maximum power dissipation point can be calculated. The package dissipation is twice the number which results from equation (1) since there are two amplifiers in each LM1876. Refer to the graphs of Power Dissipation versus Output Power in the **Typical Performance Characteristics** section which show the actual full range of power dissipation not just the maximum theoretical point that results from equation (1).

DETERMINING THE CORRECT HEAT SINK

The choice of a heat sink for a high-power audio amplifier is made entirely to keep the die temperature at a level such that the thermal protection circuitry does not operate under normal circumstances.

The thermal resistance from the die (junction) to the outside air (ambient) is a combination of three thermal resistances, θ_{JC}, θ_{CS}, and θ_{SA}. In addition, the thermal resistance, θ_{JC} (junction to case), of the LM1876 is 2°C/W. Using Thermalloy Thermacote thermal compound, the thermal resistance, θ_{CS} (case to sink), is about 0.2°C/W. Since convection heat flow (power dissipation) is analogous to current flow, thermal resistance is analogous to electrical resistance, and temperature drops are analogous to voltage drops, the power dissipation out of the LM1876 is equal to the following:

$$P_{DMAX} = (T_{JMAX} - T_{AMB})/\theta_{JA} \quad (2)$$

where $T_{JMAX} = 150°C$, T_{AMB} is the system ambient temperature and $\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$.

Once the maximum package power dissipation has been calculated using equation (1), the maximum thermal resistance, θ_{SA}, (heat sink to ambient) in °C/W for a heat sink can be calculated. This calculation is made using equation (3) which is derived by solving for θ_{SA} in equation (2).

$$\theta_{SA} = [(T_{JMAX} - T_{AMB}) - P_{DMAX}(\theta_{JC} + \theta_{CS})]/P_{DMAX} \quad (3)$$

Application Information (Continued)

Again it must be noted that the value of θ_{SA} is dependent upon the system designer's amplifier requirements. If the ambient temperature that the audio amplifier is to be working under is higher than 25°C, then the thermal resistance for the heat sink, given all other things are equal, will need to be smaller.

SUPPLY BYPASSING

The LM1876 has excellent power supply rejection and does not require a regulated supply. However, to improve system performance as well as eliminate possible oscillations, the LM1876 should have its supply leads bypassed with low-inductance capacitors having short leads that are located close to the package terminals. Inadequate power supply bypassing will manifest itself by a low frequency oscillation known as "motorboating" or by high frequency instabilities. These instabilities can be eliminated through multiple bypassing utilizing a large tantalum or electrolytic capacitor (10 μF or larger) which is used to absorb low frequency variations and a small ceramic capacitor (0.1 μF) to prevent any high frequency feedback through the power supply lines.

If adequate bypassing is not provided, the current in the supply leads which is a rectified component of the load current may be fed back into internal circuitry. This signal causes distortion at high frequencies requiring that the supplies be bypassed at the package terminals with an electrolytic capacitor of 470 μF or more.

BRIDGED AMPLIFIER APPLICATION

The LM1876 has two operational amplifiers internally, allowing for a few different amplifier configurations. One of these configurations is referred to as "bridged mode" and involves driving the load differentially through the LM1876's outputs. This configuration is shown in *Figure 2*. Bridged mode operation is different from the classical single-ended amplifier configuration where one side of its load is connected to ground.

A bridge amplifier design has a distinct advantage over the single-ended configuration, as it provides differential drive to the load, thus doubling output swing for a specified supply voltage. Consequently, theoretically four times the output power is possible as compared to a single-ended amplifier under the same conditions. This increase in attainable output power assumes that the amplifier is not current limited or clipped.

A direct consequence of the increased power delivered to the load by a bridge amplifier is an increase in internal power dissipation. For each operational amplifier in a bridge configuration, the internal power dissipation will increase by a factor of two over the single ended dissipation. Thus, for an audio power amplifier such as the LM1876, which has two operational amplifiers in one package, the package dissipation will increase by a factor of four. To calculate the LM1876's maximum power dissipation point for a bridged load, multiply equation (1) by a factor of four.

This value of P_{DMAX} can be used to calculate the correct size heat sink for a bridged amplifier application. Since the internal dissipation for a given power supply and load is increased by using bridged-mode, the heatsink's θ_{SA} will have to decrease accordingly as shown by equation (3). Refer to the section, **Determining the Correct Heat Sink,** for a more detailed discussion of proper heat sinking for a given application.

SINGLE-SUPPLY AMPLIFIER APPLICATION

The typical application of the LM1876 is a split supply amplifier. But as shown in *Figure 3*, the LM1876 can also be used in a single power supply configuration. This involves using some external components to create a half-supply bias which is used as the reference for the inputs and outputs. Thus, the signal will swing around half-supply much like it swings around ground in a split-supply application. Along with proper circuit biasing, a few other considerations must be accounted for to take advantage of all of the LM1876 functions.

The LM1876 possesses a mute and standby function with internal logic gates that are half-supply referenced. Thus, to enable either the Mute or Standby function, the voltage at these pins must be a minimum of 2.5V above half-supply. In single-supply systems, devices such as microprocessors and simple logic circuits used to control the mute and standby functions, are usually referenced to ground, not half-supply. Thus, to use these devices to control the logic circuitry of the LM1876, a "level shifter," like the one shown in *Figure 5*, must be employed. A level shifter is not needed in a split-supply configuration since ground is also half-supply.

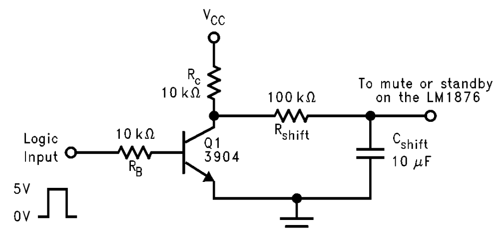


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FIGURE 5. Level Shift Circuit

When the voltage at the Logic Input node is 0V, the 2N3904 is "off" and thus resistor R_C pulls up mute or standby input to the supply. This enables the mute or standby function. When the Logic Input is 5V, the 2N3904 is "on" and consequently, the voltage at the collector is essentially 0V. This will disable the mute or standby function, and thus the amplifier will be in its normal mode of operation. R_{shift}, along with C_{shift}, creates an RC time constant that reduces transients when the mute or standby functions are enabled or disabled. Additionally, R_{shift} limits the current supplied by the internal logic gates of the LM1876 which insures device reliability. Refer to the Mute Mode and Standby Mode sections in the **Application Information** section for a more detailed description of these functions.

CLICKS AND POPS

In the typical application of the LM1876 as a split-supply audio power amplifier, the IC exhibits excellent "click" and "pop" performance when utilizing the mute and standby modes. In addition, the device employs Under-Voltage Protection, which eliminates unwanted power-up and power-down transients. The basis for these functions are a stable and constant half-supply potential. In a split-supply application, ground is the stable half-supply potential. But in a single-supply application, the half-supply needs to charge up just like the supply rail, V_{CC}. This makes the task of attaining a clickless and popless turn-on more challenging. Any uneven charging of the amplifier inputs will result in output clicks and pops due to the differential input topology of the LM1876.

Application Information (Continued)

To achieve a transient free power-up and power-down, the voltage seen at the input terminals should be ideally the same. Such a signal will be common-mode in nature, and will be rejected by the LM1876. In *Figure 3*, the resistor R_{INP} serves to keep the inputs at the same potential by limiting the voltage difference possible between the two nodes. This should significantly reduce any type of turn-on pop, due to an uneven charging of the amplifier inputs. This charging is based on a specific application loading and thus, the system designer may need to adjust these values for optimal performance.

As shown in *Figure 3*, the resistors labeled R_{BI} help bias up the LM1876 off the half-supply node at the emitter of the 2N3904. But due to the input and output coupling capacitors in the circuit, along with the negative feedback, there are two different values of R_{BI}, namely 10 kΩ and 200 kΩ. These resistors bring up the inputs at the same rate resulting in a popless turn-on. Adjusting these resistors values slightly may reduce pops resulting from power supplies that ramp extremely quick or exhibit overshoot during system turn-on.

AUDIO POWER AMPLIFIER DESIGN

Design a 15W/8Ω Audio Amplifier

Given:

Power Output	15 Wrms
Load Impedance	8Ω
Input Level	1 Vrms(max)
Input Impedance	47 kΩ
Bandwidth	20 Hz−20 kHz ±0.25 dB

A designer must first determine the power supply requirements in terms of both voltage and current needed to obtain the specified output power. V_{OPEAK} can be determined from equation (4) and I_{OPEAK} from equation (5).

$$V_{OPEAK} = \sqrt{(2R_LP_O)} \quad (4)$$

$$I_{OPEAK} = \sqrt{(2P_O)/R_L} \quad (5)$$

To determine the maximum supply voltage the following conditions must be considered. Add the dropout voltage to the peak output swing V_{OPEAK}, to get the supply rail at a current of I_{OPEAK}. The regulation of the supply determines the unloaded voltage which is usually about 15% higher. The supply voltage will also rise 10% during high line conditions. Therefore the maximum supply voltage is obtained from the following equation.

$$\text{Max supplies} \approx \pm (V_{OPEAK} + V_{OD})(1 + \text{regulation})(1.1)$$

For 15W of output power into an 8Ω load, the required V_{OPEAK} is 15.49V. A minimum supply rail of 20.5V results from adding V_{OPEAK} and V_{OD}. With regulation, the maximum supplies are ±26V and the required I_{OPEAK} is 1.94A from equation (5). It should be noted that for a dual 15W amplifier into an 8Ω load the I_{OPEAK} drawn from the supplies is twice 1.94 Apk or 3.88 Apk. At this point it is a good idea to check the Power Output vs Supply Voltage to ensure that the required output power is obtainable from the device while maintaining low THD+N. In addition, the designer should verify that with the required power supply voltage and load impedance, that the required heatsink value θ_{SA} is feasible given system cost and size constraints. Once the heatsink issues have been addressed, the required gain can be determined from Equation (6).

$$A_V \geq \sqrt{(P_OR_L)}/(V_{IN}) = V_{ORMS}/V_{INRMS} \quad (6)$$

From equation 6, the minimum A_V is: $A_V \geq 11$.

By selecting a gain of 21, and with a feedback resistor, R_f = 20 kΩ, the value of R_i follows from equation (7).

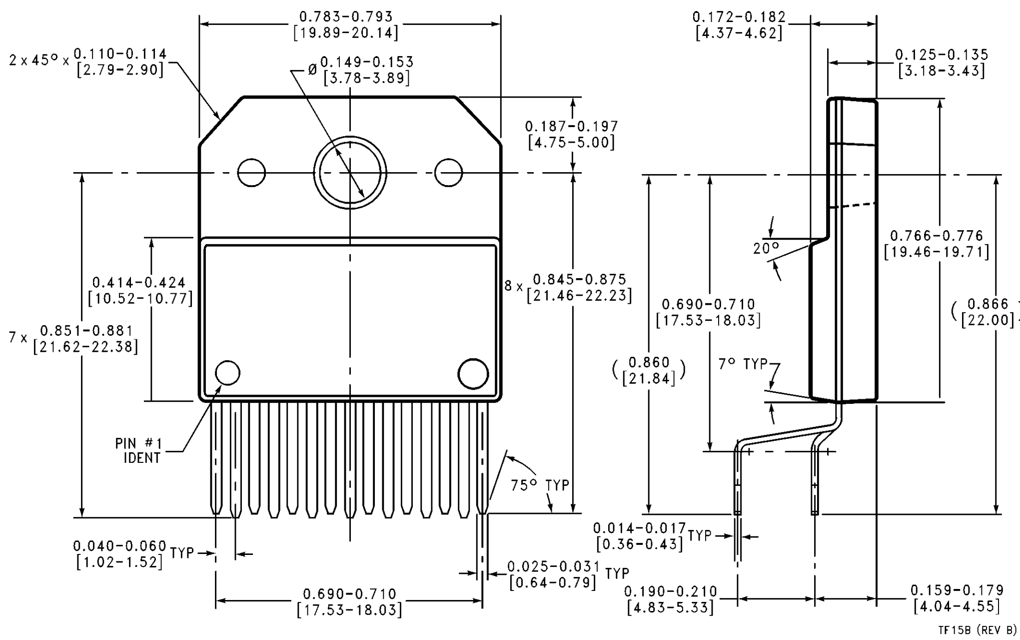
$$R_i = R_f (A_V - 1) \quad (7)$$

Thus with R_i = 1 kΩ a non-inverting gain of 21 will result. Since the desired input impedance was 47 kΩ, a value of 47 kΩ was selected for R_{IN}. The final design step is to address the bandwidth requirements which must be stated as a pair of −3 dB frequency points. Five times away from a −3 dB point is 0.17 dB down from passband response which is better than the required ±0.25 dB specified. This fact results in a low and high frequency pole of 4 Hz and 100 kHz respectively. As stated in the **External Components** section, R_i in conjunction with C_i create a high-pass filter.

$$C_i \geq 1/(2\pi * 1\text{ k}\Omega * 4\text{ Hz}) = 39.8\ \mu\text{F}; \quad \text{use } 39\ \mu\text{F}.$$

The high frequency pole is determined by the product of the desired high frequency pole, f_H, and the gain, A_V. With a A_V = 21 and f_H = 100 kHz, the resulting GBWP is 2.1 MHz, which is less than the guaranteed minimum GBWP of the LM1876 of 5 MHz. This will ensure that the high frequency response of the amplifier will be no worse than 0.17 dB down at 20 kHz which is well within the bandwidth requirements of the design.

Physical Dimensions inches (millimeters) unless otherwise noted



Isolated TO-220 15-Lead Package
Order Number LM1876TF
NS Package Number TF15B

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National Semiconductor

March 1995

LM4860 Boomer® Audio Power Amplifier Series
1W Audio Power Amplifier with Shutdown Mode

General Description

The LM4860 is a bridge-connected audio power amplifier capable of delivering 1W of continuous average power to an 8Ω load with less than 1% (THD+N) over the audio spectrum from a 5V power supply.

Boomer audio power amplifiers were designed specifically to provide high quality output power with a minimal amount of external components using surface mount packaging. Since the LM4860 does not require output coupling capacitors, bootstrap capacitors or snubber networks, it is optimally suited for low-power portable systems.

The LM4860 features an externally controlled, low-power consumption shutdown mode, as well as an internal thermal shutdown protection mechanism. It also includes two headphone control inputs and a headphone sense output for external monitoring.

The unity-gain stable LM4860 can be configured by external gain setting resistors for differential gains of 1 to 10 without the use of external compensation components.

Key Specifications

- THD+N at 1W continuous average output power into 8Ω — 1% (max)
- Instantaneous peak output power — >2W
- Shutdown current — 0.6 μA (typ)

Features

- No output coupling capacitors, bootstrap capacitors, or snubber circuits are necessary
- Small Outline (SO) power packaging
- Compatible with PC power supplies
- Thermal shutdown protection circuitry
- Unity-gain stable
- External gain configuration capability
- Two headphone control inputs and headphone sensing output

Applications

- Personal computers
- Portable consumer products
- Cellular phones
- Self-powered speakers
- Toys and games

Typical Application

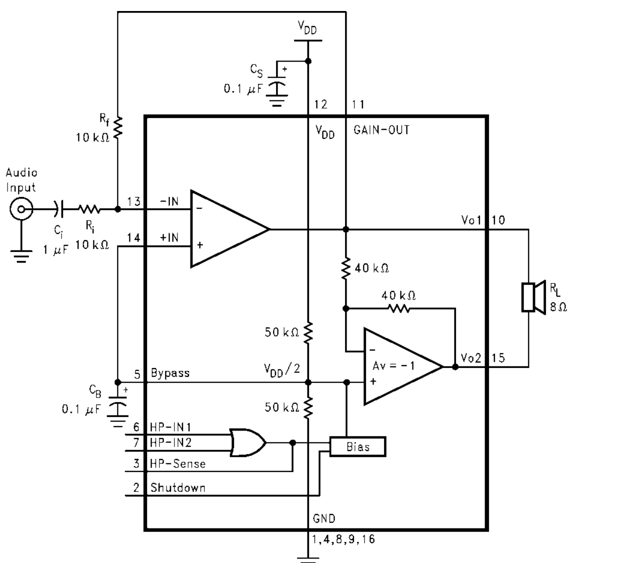

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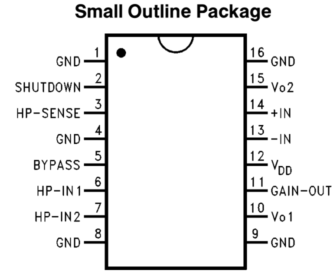
FIGURE 1. Typical Audio Amplifier Application Circuit

Connection Diagram

Small Outline Package



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Top View

Order Number LM4860M
See NS Package Number M16A

 RRD-B30M75/Printed in U. S. A.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	6.0V
Storage Temperature	−65°C to +150°C
Input Voltage	−0.3V to V_{DD} + 0.3V
Power Dissipation	Internally limited
ESD Susceptibility (Note 4)	3000V
ESD Susceptibility (Note 5)	250V
Junction Temperature	150°C

Soldering Information

Small Outline Package

Vapor Phase (60 sec.)	215°C
Infrared (15 sec.)	220°C

See AN-450 *"Surface Mounting and their Effects on Product Reliability" for other methods of soldering surface mount devices.*

Operating Ratings

Temperature Range	
$T_{MIN} \leq T_A \leq T_{MAX}$	$-20°C \leq T_A \leq +85°C$
Supply Voltage	$2.7V \leq V_{DD} \leq 5.5V$

Electrical Characteristics (Notes 1, 2)

The following specifications apply for V_{DD} = 5V, R_L = 8Ω unless otherwise specified. Limits apply for T_A = 25°C.

Symbol	Parameter	Conditions	LM4860		Units (Limits)
			Typical (Note 6)	Limit (Note 7)	
V_{DD}	Supply Voltage			2.7 5.5	V (min) V (max)
I_{DD}	Quiescent Power Supply Current	V_O = 0V, I_O = 0A (Note 8)	7.0	15.0	mA (max)
I_{SD}	Shutdown Current	V_{pin2} = V_{DD} (Note 9)	0.6		μA
V_{OS}	Output Offset Voltage	V_{IN} = 0V	5.0	50.0	mV (max)
P_O	Output Power	THD+N = 1% (max); f = 1 kHz	1.15	1.0	W (min)
THD+N	Total Harmonic Distortion + Noise	P_O = 1 Wrms; 20 Hz ≤ f ≤ 20 kHz	0.72		%
PSRR	Power Supply Rejection Ratio	V_{DD} = 4.9V to 5.1V	65		dB
V_{od}	Output Dropout Voltage	V_{IN} = 0V to 5V, $V_{od} = (V_{o1} - V_{o2})$	0.6	1.0	V (max)
V_{IH}	HP-IN High Input Voltage	HP-SENSE = 0V to 4V	2.5		V
V_{IL}	HP-IN Low Input Voltage	HP-SENSE = 4V to 0V	2.5		V
V_{OH}	HP-SENSE High Output Voltage	I_O = 500 μA	2.8	2.5	V (min)
V_{OL}	HP-SENSE Low Output Voltage	I_O = −500 μA	0.2	0.8	V (max)

Note 1: All voltages are measured with respect to the ground pins, unless otherwise specified.

Note 2: *Absolute Maximum Ratings* indicate limits beyond which damage to the device may occur. *Operating Ratings* indicate conditions for which the device is functional, but do not guarantee specific performance limits. *Electrical Characteristics* state DC and AC electrical specifications under particular test conditions which guarantee specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not guaranteed for parameters where no limit is given, however, the typical value is a good indication of device performance.

Note 3: The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{JMAX}, θ_{JA}, and the ambient temperature T_A. The maximum allowable power dissipation is $P_{DMAX} = (T_{JMAX} - T_A)/\theta_{JA}$ or the number given in the Absolute Maximum Ratings, whichever is lower. For the LM4860, T_{JMAX} = +150°C, and the typical junction-to-ambient thermal resistance, when board mounted, is 100°C/W.

Note 4: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 5: Machine Model, 200 pF–240 pF discharged through all pins.

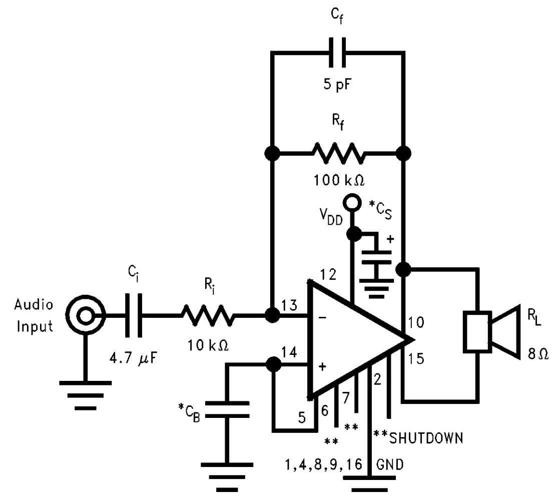
Note 6: Typicals are measured at 25°C and represent the parametric norm.

Note 7: Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 8: The quiescent power supply current depends on the offset voltage when a practical load is connected to the amplifier.

Note 9: Shutdown current has a wide distribution. For Power Management sensitive designs, contact your local National Semiconductor Sales Office.

High Gain Application Circuit



TL/H/11988–3

FIGURE 2. Stereo Amplifier with $A_{VD} = 20$

Single Ended Application Circuit

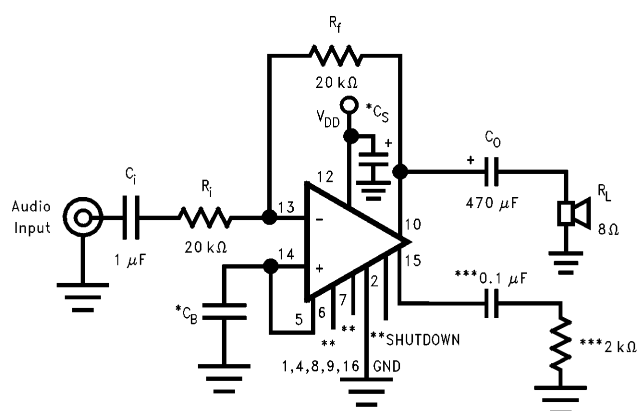


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FIGURE 3. Single-Ended Amplifier with $A_V = -1$

*C_S and C_B size depend on specific application requirements and constraints. Typical values of C_S and C_B are 0.1 μF.

**Pin 2, 6, or 7 should be connected to V_{DD} to disable the amplifier or to GND to enable the amplifier. These pins should not be left floating.

***These components create a ''dummy'' load for pin 8 for stability purposes.

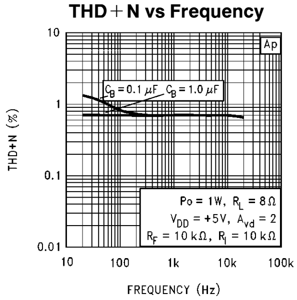
External Components Description *(Figures 1, 2)*

Components	Functional Description
1. R_i	Inverting input resistance which sets the closed-loop gain in conjunction with R_f. This resistor also forms a high pass filter with C_i at $f_C = 1/(2\pi R_i C_i)$.
2. C_i	Input coupling capacitor which blocks DC voltage at the amplifier's input terminals. Also creates a highpass filter with R_i at $f_C = 1/(2\pi R_i C_i)$.
3. R_f	Feedback resistance which sets closed-loop gain in conjunction with R_i.
4. C_S	Supply bypass capacitor which provides power supply filtering. Refer to the **Application Information** section for proper placement and selection of supply bypass capacitor.
5. C_B	Bypass pin capacitor which provides half supply filtering. Refer to **Application Information** section for proper placement and selection of bypass capacitor.
6. C_f*	Used when a differential gain of over 10 is desired. C_f in conjunction with R_f creates a low-pass filter which bandwidth limits the amplifier and prevents high frequency oscillation bursts. $f_C = 1/(2\pi R_f C_f)$

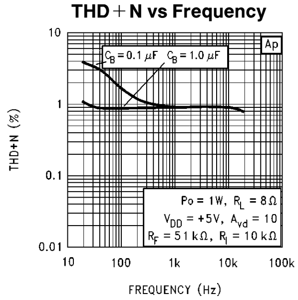
*Optional component dependent upon specific design requirements. Refer to the **Application Information** section for more in formation.

Typical Performance Characteristics

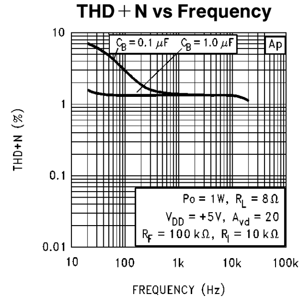
THD + N vs Frequency



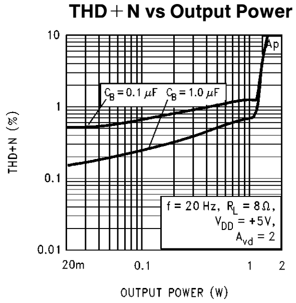
THD + N vs Frequency



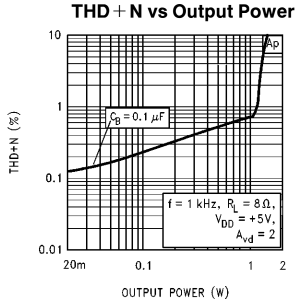
THD + N vs Frequency



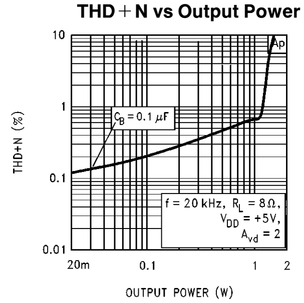
THD + N vs Output Power



THD + N vs Output Power



THD + N vs Output Power



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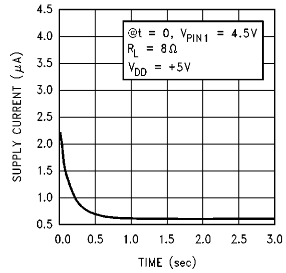
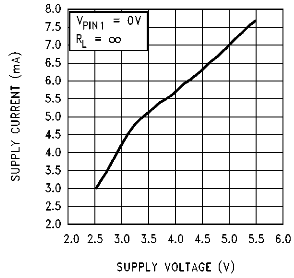
Typical Performance Characteristics (Continued)

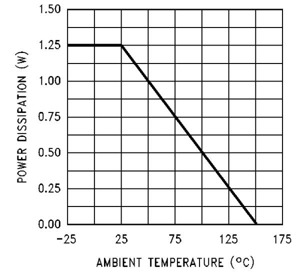
Supply Current vs Time in Shutdown Mode



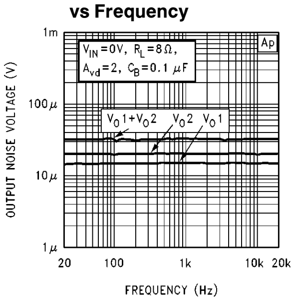
Supply Current vs Supply Voltage



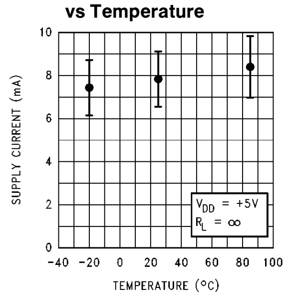
Power Derating Curve



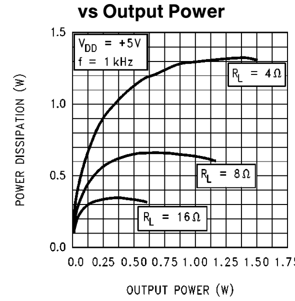
LM4860 Noise Floor vs Frequency



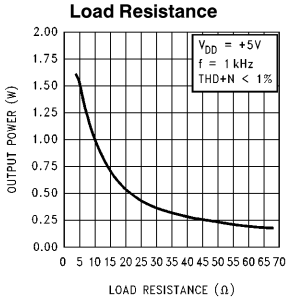
Supply Current Distribution vs Temperature



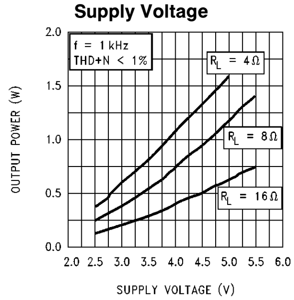
Power Dissipation vs Output Power



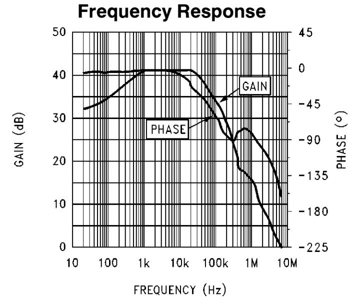
Output Power vs Load Resistance



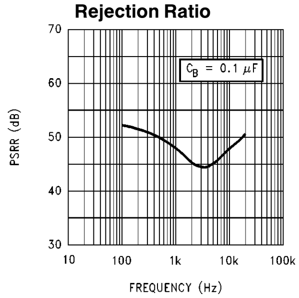
Output Power vs Supply Voltage



Open Loop Frequency Response



Power Supply Rejection Ratio



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Application Information

BRIDGE CONFIGURATION EXPLANATION

As shown in *Figure 1*, the LM4860 has two operational amplifiers internally, allowing for a few different amplifier configurations. The first amplifier's gain is externally configurable, while the second amplifier is internally fixed in a unity-gain, inverting configuration. The closed-loop gain of the first amplifier is set by selecting the ratio of R_f to R_i while the second amplifier's gain is fixed by the two internal 40 kΩ resistors. *Figure 1* shows that the output of amplifier one serves as the input to amplifier two which results in both amplifiers producing signals identical in magnitude, but out of phase 180°. Consequently, the differential gain for the IC is:

$$A_{vd} = 2 * (R_f/R_i)$$

By driving the load differentially through outputs V_{O1} and V_{O2}, an amplifier configuration commonly referred to as "bridged mode" is established. Bridged mode operation is different from the classical single-ended amplifier configuration where one side of its load is connected to ground.

A bridge amplifier design has a few distinct advantages over the single-ended configuration, as it provides differential drive to the load, thus doubling output swing for a specified supply voltage. Consequently, four times the output power is possible as compared to a single-ended amplifier under the same conditions. This increase in attainable output power assumes that the amplifier is not current limited or clipped. In order to choose an amplifier's closed-loop gain without causing excessive clipping which will damage high frequency transducers used in loudspeaker systems, please refer to the **Audio Power Amplifier Design** section.

A bridge configuration, such as the one used in Boomer Audio Power Amplifiers, also creates a second advantage over single-ended amplifiers. Since the differential outputs, V_{O1} and V_{O2}, are biased at half-supply, no net DC voltage exists across the load. This eliminates the need for an output coupling capacitor which is required in a single supply, single-ended amplifier configuration. Without an output coupling capacitor in a single supply single-ended amplifier, the half-supply bias across the load would result in both increased internal IC power dissipation and also permanent loudspeaker damage. An output coupling capacitor forms a high pass filter with the load requiring that a large value such as 470 µF be used with an 8Ω load to preserve low frequency response. This combination does not produce a flat response down to 20 Hz, but does offer a compromise between printed circuit board size and system cost, versus low frequency response.

POWER DISSIPATION

Power dissipation is a major concern when designing a successful amplifier, whether the amplifier is bridged or single-ended. A direct consequence of the increased power delivered to the load by a bridge amplifier is an increase in internal power dissipation. Equation 1 states the maximum power dissipation point for a bridge amplifier operating at a given supply voltage and driving a specified output load.

$$P_{DMAX} = 4 * (V_{DD})^2/(2\pi^2 R_L) \quad (1)$$

Since the LM4860 has two operational amplifiers in one package, the maximum internal power dissipation is 4 times that of a single-ended amplifier. Even with this substantial increase in power dissipation, the LM4860 does not require heatsinking. From Equation 1, assuming a 5V power supply and an 8Ω load, the maximum power dissipation point is 625 mW. The maximum power dissipation point obtained from Equation 1 must not be greater than the power dissipation that results from Equation 2:

$$P_{DMAX} = (T_{JMAX} - T_A)/\theta_{JA} \quad (2)$$

For the LM4860 surface mount package, θ_{JA} = 100°C/W and T_{JMAX} = 150°C. Depending on the ambient temperature, T_A, of the system surroundings, Equation 2 can be used to find the maximum internal power dissipation supported by the IC packaging. If the result of Equation 1 is greater than that of Equation 2, then either the supply voltage must be decreased or the load impedance increased. For the typical application of a 5V power supply, with an 8Ω load, the maximum ambient temperature possible without violating the maximum junction temperature is approximately 88°C, provided that device operation is around the maximum power dissipation point. Power dissipation is a function of output power and thus, if typical operation is not around the maximum power dissipation point, the ambient temperature can be increased. Refer to the **Typical Performance Characteristics** curves for power dissipation information for lower output powers.

POWER SUPPLY BYPASSING

As with any power amplifier, proper supply bypassing is critical for low noise performance and high power supply rejection. The capacitor location on both the bypass and power supply pins should be as close to the device as possible. As displayed in the **Typical Performance Characteristics** section, the effect of a larger half-supply bypass capacitor is improved low frequency THD+N due to increased half-supply stability. Typical applications employ a 5V regulator with 10 µF and a 0.1 µF bypass capacitors which aid in supply stability, but do not eliminate the need for bypassing the supply nodes of the LM4860. The selection of bypass capacitors, especially C_B, is thus dependant upon desired low frequency THD+N, system cost, and size constraints.

SHUTDOWN FUNCTION

In order to reduce power consumption while not in use, the LM4860 contains a shutdown pin to externally turn off the amplifier's bias circuitry. The shutdown feature turns the amplifier off when a logic high is placed on the shutdown pin. Upon going into shutdown, the output is immediately disconnected from the speaker. There is a built-in threshold which produces a drop in quiescent current to 500 µA typically. For a 5V power supply, this threshold occurs when 2V–3V is applied to the shutdown pin. A typical quiescent current of 0.6 µA results when the supply voltage is applied to the shutdown pin. In many applications, a microcontroller or microprocessor output is used to control the shutdown circuitry which provides a quick, smooth transition into shutdown. Another solution is to use a single-pole, single-throw switch that when closed, is connected to ground and enables the amplifier. If the switch is open, then a soft pull-up resistor of 47 kΩ will disable the LM4860. There are no soft pull-down resistors inside the LM4860, so a definite shutdown pin voltage must be appliied externally, or the internal logic gate will be left floating which could disable the amplifier unexpectedly.

Application Information (Continued)

HEADPHONE CONTROL INPUTS

The LM4860 possesses two headphone control inputs that disable the amplifier and reduce I_{DD} to less than 1 mA when either one or both of these inputs have a logic-high voltage placed on their pins.

Unlike the shutdown function, the headphone control function does not provide the level of current conservation that is required for battery powered systems. Since the quiescent current resulting from the headphone control function is 1000 times more than the shutdown function, the residual currents in the device may create a pop at the output when coming out of the headphone control mode. The pop effect may be eliminated by connecting the headphone sensing output to the shutdown pin input as shown in *Figure 4.* This solution will not only eliminate the output pop, but will also utilize the full current conservation of the shutdown function by reducing I_{DD} to 0.6 μA. The amplifier will then be fully shutdown. This configuration also allows the designer to use the control inputs as either two headphone control pins or a headphone control pin and a shutdown pin where the lowest level of current consumption is obtained from either function.

Figure 5 shows the implementation of the LM4860's headphone control function using a single-supply headphone amplifier. The voltage divider of R1 and R2 sets the voltage at the HP-IN1 pin to be approximately 50 mV when there are no headphones plugged into the system. This logic-low voltage at the HP-IN1 pin enables the LM4860 to amplify AC signals. Resistor R3 limits the amount of current flowing out of the HP-IN1 pin when the voltage at that pin goes below ground resulting from the music coming from the headphone amplifier. The output coupling cap protects the headphones by blocking the amplifier's half-supply DC voltage. The capacitor also protects the headphone amplifier from the low voltage set up by resistors R1 and R2 when there aren't any headphones plugged into the system. The tricky point to this setup is that the AC output voltage of the headphone amplifier cannot exceed the 2.0V HP-IN1 voltage threshold when there aren't any headphones plugged into the system, assuming that R1 and R2 are 100k and 1k, respectively. The LM4860 may not be fully shutdown when this level is exceeded momentarily, due to the discharging time constant of the bias-pin voltage. This time constant is established by the two 50k resistors (in parallel) with the series bypass capacitor value.

When a set of headphones are plugged into the system, the contact pin of the headphone jack is disconnected from the signal pin, interrupting the voltage divider set up by resistors R1 and R2. Resistor R1 then pulls up the HP-IN1 pin, enabling the headphone function and disabling the LM4860 amplifier. The headphone amplifier then drives the headphones, whose impedance is in parallel with resistor R2. Since the typical impedance of headphones are 32Ω, resistor R2 has negligible effect on the output drive capability. Also shown in *Figure 5* are the electrical connections for the headphone jack and plug. A 3-wire plug consists of a Tip, Ring, and Sleave, where the Tip and Ring are signal carrying conductors and the Sleave is the common ground return. One control pin contact for each headphone jack is sufficient to indicate to control inputs that the user has inserted a plug into a jack and that another mode of operation is desired.

For a system implementation where the headphone amplifier is designed using a split supply, the output coupling cap, C_C and resistor R2 of *Figure 5,* can be eliminated. The functionality described earlier remains the same, however.

In addition, the HP-SENSE pin, although it may be connected to the SHUTDOWN pin as shown in *Figure 4,* may still be used as a control flag. It is capable of driving the input to another logic gate or approximately 2 mA without serious loading.

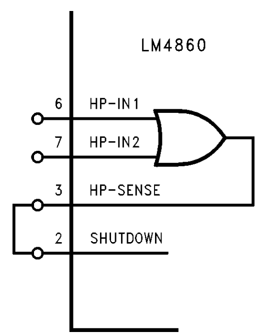

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FIGURE 4. HP-SENSE Pin to SHUTDOWN Pin Connection

Application Information (Continued)

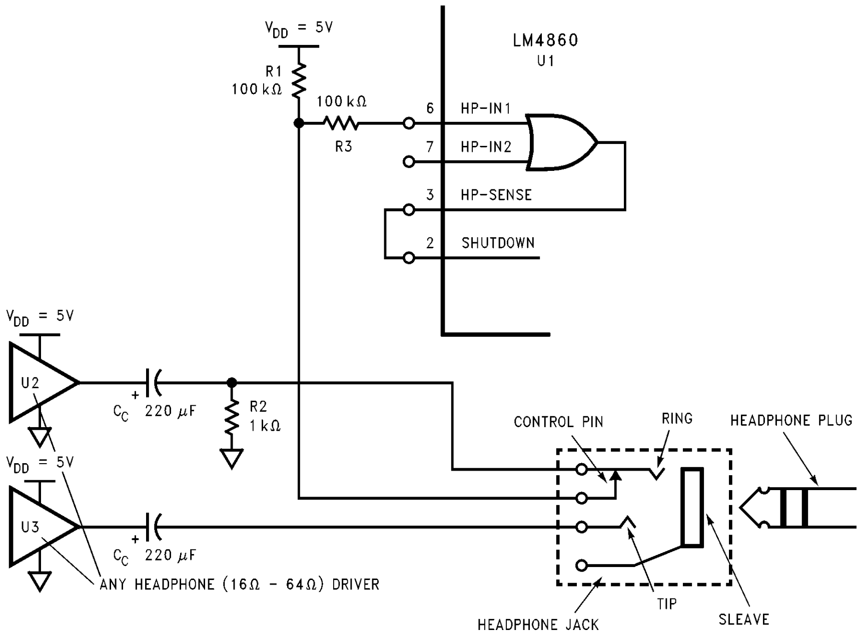


FIGURE 5. Typical Headphone Control Input Circuitry

Application Information (Continued)

HIGHER GAIN AUDIO AMPLIFIER

The LM4860 is unity-gain stable and requires no external components besides gain-setting resistors, an input coupling capacitor, and proper supply bypassing in the typical application. However if a closed-loop differential gain of greater than 10 is required, then a feedback capacitor is needed, as shown in *Figure 2,* to bandwidth limit the amplifier. The feedback capacitor creates a low pass filter that eliminates unwanted high frequency oscillations. Care should be taken when calculating the −3 dB frequency in that an incorrect combination of R_f and C_f will cause rolloff before 20 kHz. A typical combination of feedback resistor and capacitor that will not produce audio band high frequency rolloff is $R_f = 100\ k\Omega$ and $C_f = 5\ pF$. These components result in a −3 dB point of approximately 320 kHz. Once the differential gain of the amplifier has been calculated, a choice of R_f will result, and C_f can then be calculated from the formula stated in the **External Components Description** section.

VOICE-BAND AUDIO AMPLIFIER

Many applications, such as telephony, only require a voice-band frequency response. Such an application usually requires a flat frequency response from 300 Hz to 3.5 kHz. By adjusting the component values of *Figure 2,* this common application requirement can be implemented. The combination of R_i and C_i form a highpass filter while R_f and C_f form a lowpass filter. Using the typical voice-band frequency range, with a passband differential gain of approximately 100, the following values of R_i, C_i, R_f, and C_f follow from the equations stated in the **External Components Description** section.

$$R_i = 10\ k\Omega,\ R_f = 510k,\ C_i = 0.22\ \mu F,\ \text{and}\ C_f = 15\ pF$$

Five times away from a −3 dB point is 0.17 dB down from the flatband response. With this selection of components, the resulting −3 dB points, f_L and f_H, are 72 Hz and 20 kHz, respectively, resulting in a flatband frequency response of better than ±0.25 dB with a rolloff of 6 dB/octave outside of the passband. If a steeper rolloff is required, other common bandpass filtering techniques can be used to achieve higher order filters.

SINGLE-ENDED AUDIO AMPLIFIER

Although the typical application for the LM4860 is a bridged monoaural amp, it can also be used to drive a load single-endedly in applications, such as PC cards, which require that one side of the load is tied to ground. *Figure 3* shows a common single-ended application, where V_{O1} is used to drive the speaker. This output is coupled through a 470 µF capacitor, which blocks the half-supply DC bias that exists in all single-supply amplifier configurations. This capacitor, designated C_O in *Figure 3,* in conjunction with R_L, forms a highpass filter. The −3 dB point of this highpass filter is $1/(2\pi R_L C_O)$, so care should be taken to make sure that the product of R_L and C_O is large enough to pass low frequencies to the load. When driving an 8Ω load, and if a full audio spectrum reproduction is required, C_O should be at least 470 µF. V_{O2}, the output that is not used, is connected through a 0.1 µF capacitor to a 2 kΩ load to prevent instability. While such an instability will not affect the waveform of V_{O1}, it is good design practice to load the second output.

AUDIO POWER AMPLIFIER DESIGN

Design a 500 mW/8Ω Audio Amplifier

Given:

Power Output	500 mWrms
Load Impedance	8Ω
Input Level	1 Vrms(max)
Input Impedance	20 kΩ
Bandwidth	20 Hz-20 kHz ±0.25 dB

A designer must first determine the needed supply rail to obtain the specified output power. Calculating the required supply rail involves knowing two parameters, V_{opeak} and also the dropout voltage. The latter is typically 0.7V. V_{opeak} can be determined from equation 3.

$$V_{opeak} = \sqrt{(2\ R_L\ P_O)} \quad (3)$$

For 500 mW of output power into an 8Ω load, the required V_{opeak} is 2.83V. A minimum supply rail of 3.53V results from adding V_{opeak} and V_{od}. But 3.53V is not a standard voltage that exists in many applications and for this reason, a supply rail of 5V is designated. Extra supply voltage creates dynamic headroom that allows the LM4860 to reproduce peaks in excess of 500 mW without clipping the signal. At this time, the designer must make sure that the power supply choice along with the output impedance does not violate the conditions explained in the **Power Dissipation** section.

Once the power dissipation equations have been addressed, the required differential gain can be determined from Equation 4.

$$A_{vd} \geq 2 * \sqrt{(P_O\ R_L)}\,/(V_{IN}) = V_{orms}/V_{inrms} \quad (4)$$

$$R_f/R_i = A_{vd}/2 \quad (5)$$

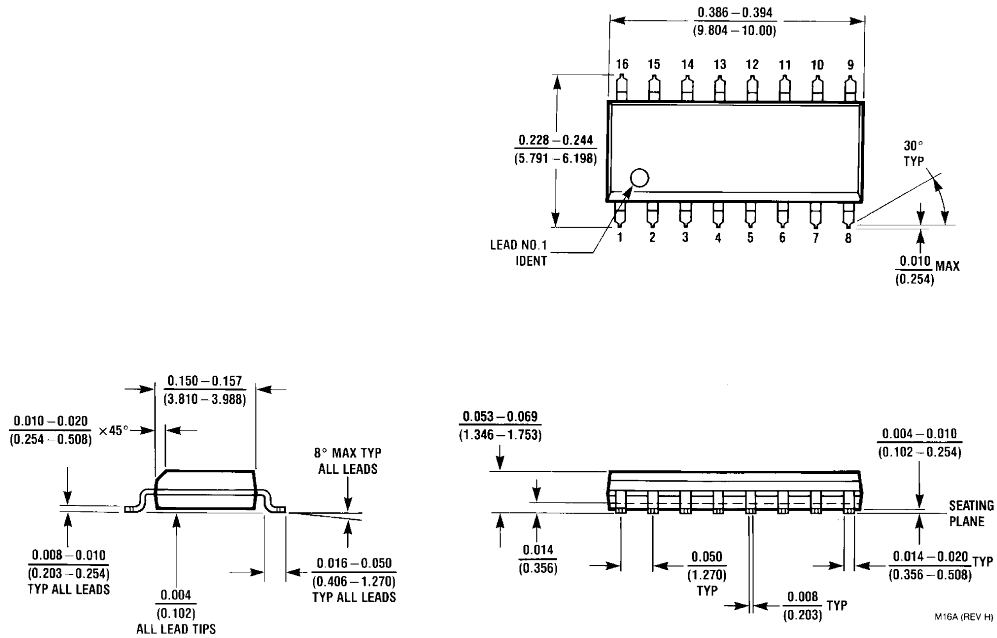
From equation 4, the minimum A_{vd} is: $A_{vd} = 2$

Since the desired input impedance was 20 kΩ, and with an A_{vd} of 2, a ratio of 1:1 of R_f to R_i results in an allocation of $R_i = R_f = 20\ k\Omega$. Since the A_{vd} was less than 10, a feedback capacitor is not needed. The final design step is to address the bandwidth requirements which must be stated as a pair of −3 dB frequency points. Five times away from a −3 dB point is 0.17 dB down from passband response which is better than the required ±0.25 dB specified. This fact results in a low and high frequency pole of 4 Hz and 100 kHz respectively. As stated in the **External Components** section, R_i in conjunction with C_i create a highpass filter.

$$C_i \geq 1/(2\pi * 20\ k\Omega * 4\ Hz) = 1.98\ \mu F; \quad \text{use } 2.2\ \mu F.$$

The high frequency pole is determined by the product of the desired high frequency pole, f_H, and the differential gain, A_{vd}. With a $A_{vd} = 2$ and $f_H = 100$ kHz, the resulting GBWP = 100 kHz which is much smaller than the LM4860 GBWP of 7 MHz. This figure displays that if a designer has a need to design an amplifier with a higher differential gain, the LM4860 can still be used without running into bandwidth problems.

Physical Dimensions inches (millimeters)



Small Outline Package (M)
Order Number LM4860M
NS Package Number M16A

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National Semiconductor

November 1995

LM4880 Boomer® Audio Power Amplifier Series
Dual 250 mW Audio Power Amplifier with Shutdown Mode

General Description

The LM4880 is a dual audio power amplifier capable of delivering typically 250 mW per channel of continuous average power to an 8Ω load with 0.1% (THD) using a 5V power supply.

Boomer audio power amplifiers were designed specifically to provide high quality output power with a minimal amount of external components using surface mount packaging.

Since the LM4880 does not require bootstrap capacitors or snubber networks, it is optimally suited for low-power portable systems.

The LM4880 features an externally controlled, low-power consumption shutdown mode, as well as an internal thermal shutdown protection mechanism.

The unity-gain stable LM4880 can be configured by external gain-setting resistors.

Key Specifications

- THD at 1 kHz at 200 mW continuous average output power into 8Ω — 0.1% (max)
- THD at 1 kHz at 85 mW continuous average output power into 32Ω — 0.1% (typ)
- Output power at 10% THD + N at 1 kHz into 8Ω — 325 mW (typ)
- Shutdown Current — 0.7 μA (typ)

Features

- No bootstrap capacitors or snubber circuits are necessary
- Small Outline (SO) and DIP packaging
- Unity-gain stable
- External gain configuration capability

Applications

- Headphone Amplifier
- Personal Computers
- CD-ROM Players

Typical Application

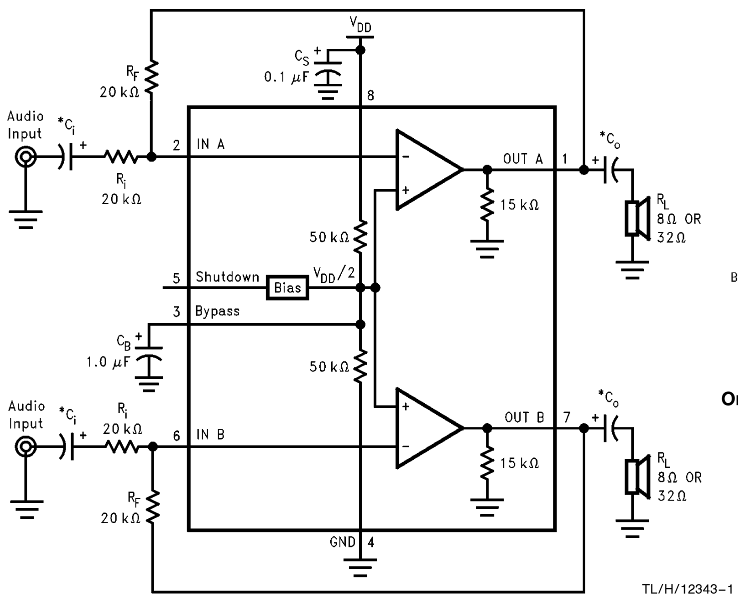
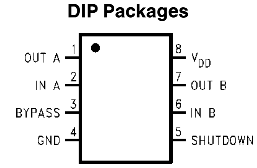


FIGURE 1. Typical Audio Amplifier Application Circuit

*Refer to the **Application Information** section for information concerning proper selection of the input and output coupling capacitors.

Connection Diagram

Small Outline and DIP Packages



TL/H/12343–2

Top View

Order Number LM4880M or LM4880N
See NS Package Number M08A for SO or NS Package Number N08E for DIP

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	6.0V
Storage Temperature	$-65°C$ to $+150°C$
Input Voltage	$-0.3V$ to $V_{DD} + 0.3V$
Power Dissipation (Note 3)	Internally limited
ESD Susceptibility (Note 4)	3500V
ESD Susceptibility (Note 5)	250V
Junction Temperature	150°C
Soldering Information	
Small Outline Package	
Vapor Phase (60 sec.)	215°C
Infrared (15 sec.)	220°C

See AN-450 "Surface Mounting and their Effects on Product Reliability" for other methods of soldering surface mount devices.

Thermal Resistance	
θ_{JC} (DIP)	37°C/W
θ_{JA} (DIP)	107°C/W
θ_{JC} (SO)	35°C/W
θ_{JA} (SO)	170°C/W

Operating Ratings

Temperature Range	
$T_{MIN} \le T_A \le T_{MAX}$	$-40°C \le T_A \le +85°C$
Supply Voltage	$2.7V \le V_{DD} \le 5.5V$

Electrical Characteristics

(Notes 1, 2) The following specifications apply for $V_{DD} = 5V$ unless otherwise specified. Limits apply for $T_A = 25°C$.

Symbol	Parameter	Conditions	LM4880 Typical (Note 6)	LM4880 Limit (Note 7)	Units (Limits)
V_{DD}	Supply Voltage			2.7 5.5	V (min) V (max)
I_{DD}	Quiescent Power Supply Current	$V_{IN}=0V$, $I_O=0A$	3.6	6.0	mA (max)
I_{SD}	Shutdown Current	$V_{PIN5}=V_{DD}$	0.7	5	µA (max)
V_{OS}	Output Offset Voltage	$V_{IN}=0V$	5	50	mV (max)
P_O	Output Power	THD=0.1% (max); f=1 kHz; $R_L=8\Omega$ $R_L=32\Omega$ THD+N=10%; f=1 kHz $R_L=8\Omega$ $R_L=32\Omega$	 250 85 325 110	 200	 mW (min) mW mW mW
THD+N	Total Harmonic Distortion+Noise	$R_L=8\Omega$, $P_O=200$ mW; $R_L=32\Omega$, $P_O=75$ mW; f=1 kHz	0.03 0.02		% %
PSRR	Power Supply Rejection Ratio	$C_B = 1.0\ \mu F$, $V_{RIPPLE}=200$ mVrms, f = 100 Hz	50		dB

Note 1: All voltages are measured with respect to the ground pin, unless otherwise specified.

Note 2: *Absolute Maximum Ratings* indicate limits beyond which damage may occur. *Operating Ratings* indicate conditions for which the device is functional, but do not guarantee specific performance limits. *Electrical Characteristics* state DC and AC electrical specifications under particular test conditions which guarantee specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not guaranteed for parameters where no limit is given, however, the typical value is a good indication of device performance.

Note 3: The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{JMAX}, θ_{JA}, and the ambient temperature T_A. The maximum allowable power dissipation is $P_{DMAX} = (T_{JMAX} - T_A)/\theta_{JA}$ or the number given in the Absolute Maximum Ratings, whichever is lower. For the LM4880, $T_{JMAX} = 150°C$, and the typical junction-to-ambient thermal resistance is 170°C/W for package M08A and 107°C/W for package N08E.

Note 4: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 5: Machine model, 220 pF–240 pF discharged through all pins.

Note 6: Typicals are measured at 25°C and represent the parametric norm.

Note 7: Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

Automatic Shutdown Circuit

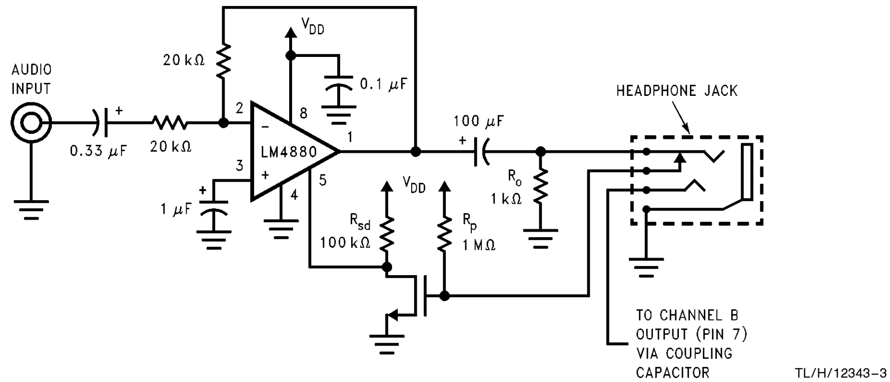


FIGURE 2. Automatic Shutdown Circuit

Automatic Switching Circuit

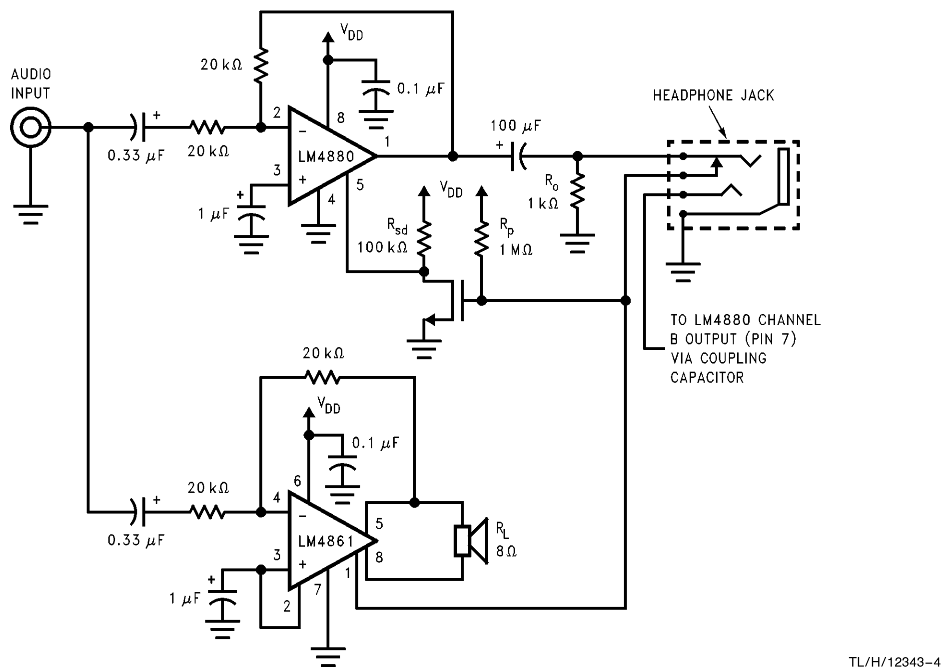


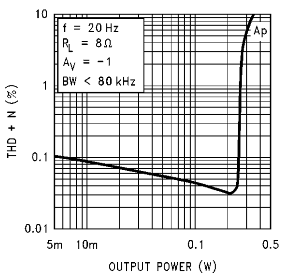
FIGURE 3. Automatic Switching Circuit

External Components Description (Figure 1)

Components		Functional Description
1.	R_i	Inverting input resistance which sets the closed-loop gain in conjunction with R_F. This resistor also forms a high pass filter with C_i at $f_c = 1/(2\pi R_i C_i)$.
2.	C_i	Input coupling capacitor which blocks the DC voltage at the amplifier's input terminals. Also creates a high pass filter with R_i at $f_c = 1/(2\pi R_i C_i)$. Refer to the section, **Proper Selection of External Components,** for an explanation of how to determine the value of C_i.
3.	R_F	Feedback resistance which sets closed-loop gain in conjunction with R_i.
4.	C_S	Supply bypass capacitor which provides power supply filtering. Refer to the **Application Information** section for proper placement and selection of the supply bypass capacitor.
5.	C_B	Bypass pin capacitor which provides half-supply filtering. Refer to the section, **Proper Selection of External Components,** for information concerning proper placement and selection of C_B.
6.	C_o	Output coupling capacitor which blocks the DC voltage at the amplifier's output. Forms a high pass filter with R_L at $f_o = 1/(2\pi R_L C_o)$.

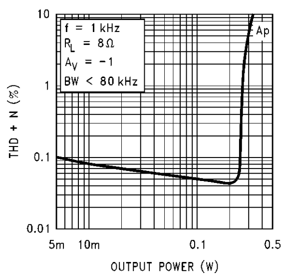
Typical Performance Characteristics

THD + N vs Output Power



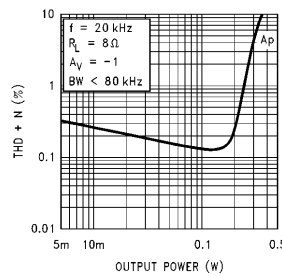
TL/H/12343–5

THD + N vs Output Power



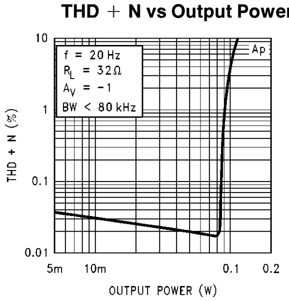
TL/H/12343–6

THD + N vs Output Power



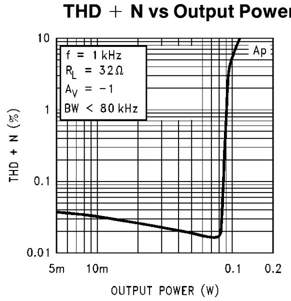
TL/H/12343–7

THD + N vs Output Power



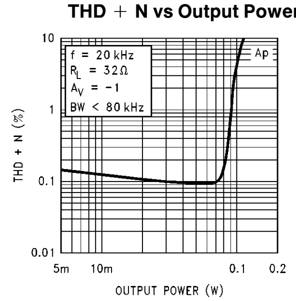
TL/H/12343–8

THD + N vs Output Power



TL/H/12343–9

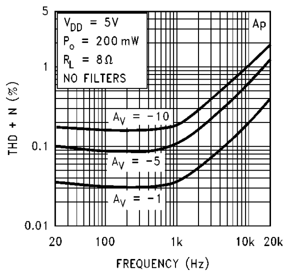
THD + N vs Output Power



TL/H/12343–10

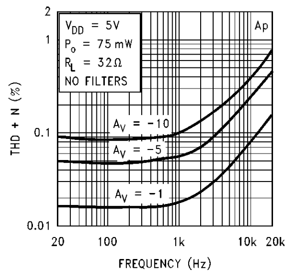
Typical Performance Characteristics (Continued)

THD + N vs Frequency



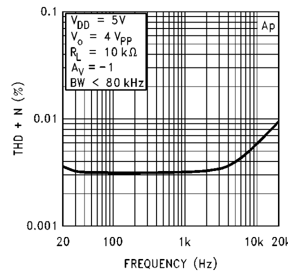
TL/H/12343–11

THD + N vs Frequency



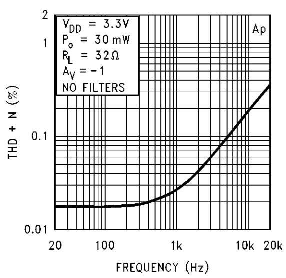
TL/H/12343–12

THD + N vs Frequency



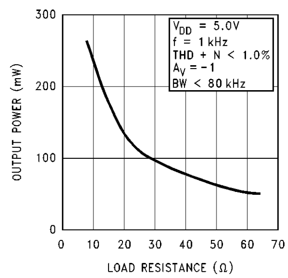
TL/H/12343–13

THD + N vs Frequency



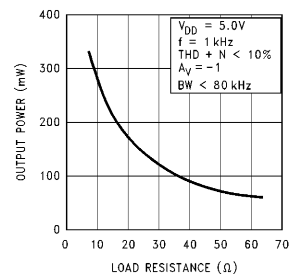
TL/H/12343–14

Output Power vs Load Resistance



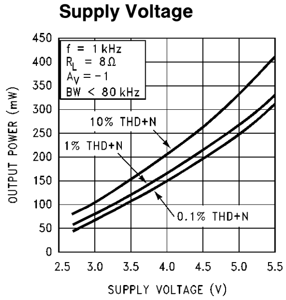
TL/H/12343–15

Output Power vs Load Resistance



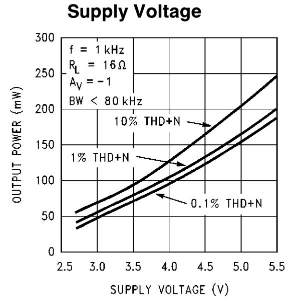
TL/H/12343–16

Output Power vs Supply Voltage



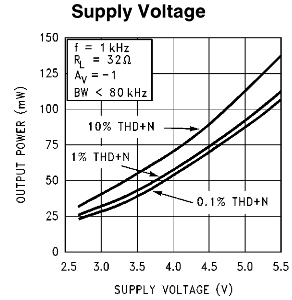
TL/H/12343–17

Output Power vs Supply Voltage



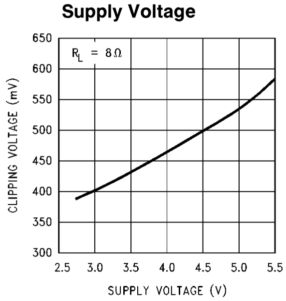
TL/H/12343–18

Output Power vs Supply Voltage



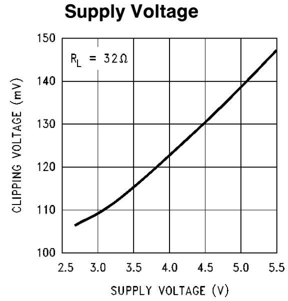
TL/H/12343–19

Clipping Voltage vs Supply Voltage



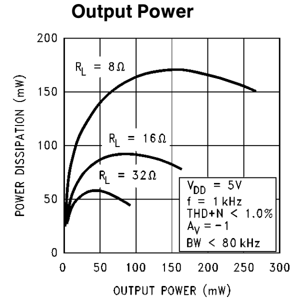
TL/H/12343–20

Clipping Voltage vs Supply Voltage



TL/H/12343–21

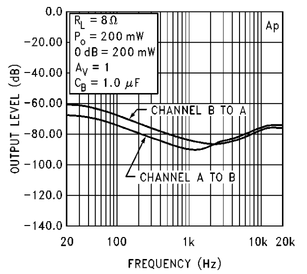
Power Dissipation vs Output Power



TL/H/12343–22

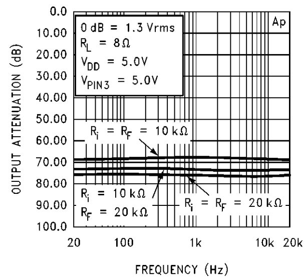
Typical Performance Characteristics (Continued)

Channel Separation



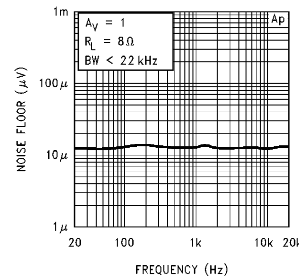
TL/H/12343–23

Output Attenuation in Shutdown Mode



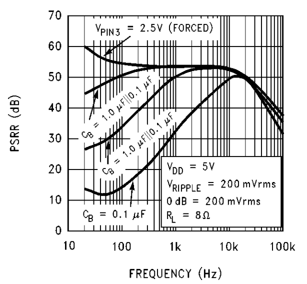
TL/H/12343–24

Noise Floor



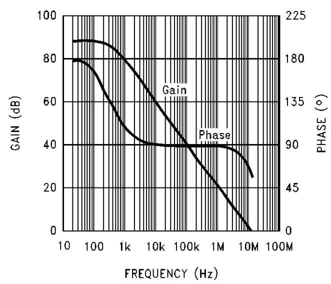
TL/H/12343–25

Power Supply Rejection Ratio



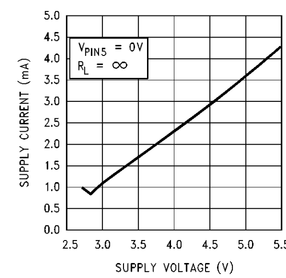
TL/H/12343–26

Open Loop Frequency Response



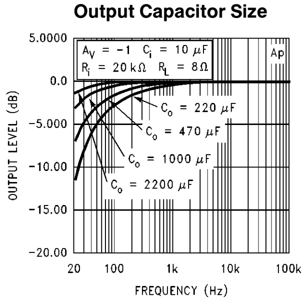
TL/H/12343–27

Supply Current vs Supply Voltage



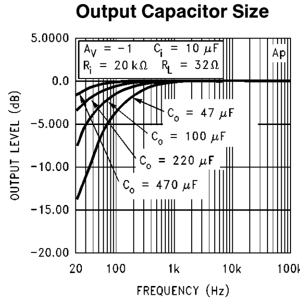
TL/H/12343–28

Frequency Response vs Output Capacitor Size



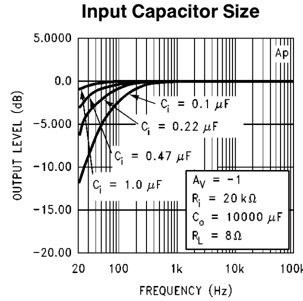
TL/H/12343–29

Frequency Response vs Output Capacitor Size



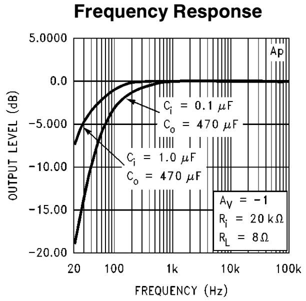
TL/H/12343–30

Frequency Response vs Input Capacitor Size



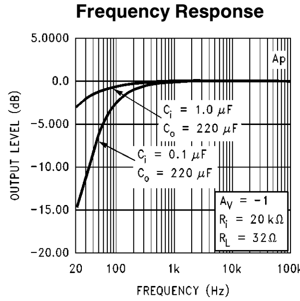
TL/H/12343–31

Typical Application Frequency Response



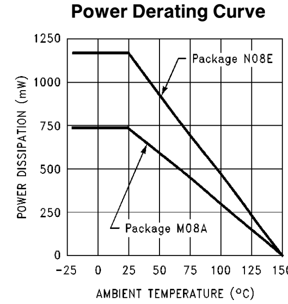
TL/H/12343–32

Typical Application Frequency Response



TL/H/12343–33

Power Derating Curve



TL/H/12343–34

Application Information

SHUTDOWN FUNCTION

In order to reduce power consumption while not in use, the LM4880 contains a shutdown pin to externally turn off the amplifier's bias circuitry. This shutdown feature turns the amplifier off when a logic high is placed on the shutdown pin. The trigger point between a logic low and logic high level is typically half supply. It is best to switch between ground and the supply to provide maximum device performance. By switching the shutdown pin to V_{DD}, the LM4880 supply current draw will be minimized in idle mode. While the device will be disabled with shutdown pin voltages less than V_{DD}, the idle current may be greater than the typical value of 0.7 μA. In either case, the shutdown pin should be tied to a definite voltage because leaving the pin floating may result in an unwanted shutdown condition.

In many applications, a microcontroller or microprocessor output is used to control the shutdown circuitry which provides a quick, smooth transition into shutdown. Another solution is to use a single-pole, single-throw switch in conjunction with an external pull-up resistor. When the switch is closed, the shutdown pin is connected to ground and enables the amplifier. If the switch is open, then the external pull-up resistor will disable the LM4880. This scheme guarantees that the shutdown pin will not float which will prevent unwanted state changes.

POWER DISSIPATION

Power dissipation is a major concern when using any power amplifier and must be thoroughly understood to ensure a successful design. Equation 1 states the maximum power dissipation point for a single-ended amplifier operating at a given supply voltage and driving a specified output load.

$$P_{DMAX} = (V_{DD})^2/(2\pi^2 R_L) \quad (1)$$

Since the LM4880 has two operational amplifiers in one package, the maximum internal power dissipation point is twice that of the number which results from Equation 1. Even with the large internal power dissipation, the LM4880 does not require heat sinking over a large range of ambient temperatures. From Equation 1, assuming a 5V power supply and an 8Ω load, the maximum power dissipation point is 158 mW per amplifier. Thus the maximum package dissipation point is 317 mW. The maximum power dissipation point obtained must not be greater than the power dissipation that results from Equation 2:

$$P_{DMAX} = (T_{JMAX}-T_A)/\theta_{JA} \quad (2)$$

For the LM4880 surface mount package, θ_{JA} = 170° C/W and T_{JMAX} = 150°C. Depending on the ambient temperature, T_A, of the system surroundings, Equation 2 can be used to find the maximum internal power dissipation supported by the IC packaging. If the result of Equation 1 is greater than that of Equation 2, then either the supply voltage must be decreased, the load impedance increased, or the ambient temperature reduced. For the typical application of a 5V power supply, with an 8Ω load, the maximum ambient temperature possible without violating the maximum junction temperature is approximately 96°C provided that device operation is around the maximum power dissipation point. Power dissipation is a function of output power and thus, if typical operation is not around the maximum power dissipation point, the ambient temperature may be increased accordingly. Refer to the **Typical Performance Characteristics** curves for power dissipation information for lower output powers.

POWER SUPPLY BYPASSING

As with any power amplifier, proper supply bypassing is critical for low noise performance and high power supply rejection. The capacitor location on both the bypass and power supply pins should be as close to the device as possible. As displayed in the **Typical Performance Characteristics** section, the effect of a larger half supply bypass capacitor is improved low frequency PSRR due to increased half-supply stability. Typical applications employ a 5V regulator with 10 μF and a 0.1 μF bypass capacitors which aid in supply stability, but do not eliminate the need for bypassing the supply nodes of the LM4880. The selection of bypass capacitors, especially C_B, is thus dependant upon desired low frequency PSRR, click and pop performance as explained in the section, **Proper Selection of External Components** section, system cost, and size constraints.

AUTOMATIC SHUTDOWN CIRCUIT

As shown in *Figure 2,* the LM4880 can be set up to automatically shutdown when a load is not connected. This circuit is based upon a single control pin common in many headphone jacks. This control pin forms a normally closed switch with one of the output pins. The output of this circuit (the voltage on pin 5 of the LM4880) has two states based on the state of the switch. When the switch is open, signifying that headphones are inserted, the LM4880 should be enabled. When the switch is closed, the LM4880 should be off to minimize power consumption.

The operation of this circuit is rather simple. With the switch closed, R_p and R_o form a resistor divider which produces a gate voltage of less than 5 mV. This gate voltage keeps the NMOS inverter off and R_{sd} pulls the shutdown pin of the LM4880 to the supply voltage. This places the LM4880 in shutdown mode which reduces the supply current to 0.7 μA typically. When the switch is open, the opposite condition is produced. Resistor R_p pulls the gate of the NMOS high which turns on the inverter and produces a logic low signal on the shutdown pin of the LM4880. This state enables the LM4880 and places the amplifier in its normal mode of operation.

This type of circuit is clearly valuable in portable products where battery life is critical, but is also benefical for power conscious designs such as ''Green PC's''.

AUTOMATIC SWITCHING CIRCUIT

A circuit closely related to the **Automatic Shutdown Circuit** is the **Automatic Switching Circuit** of *Figure 3.* The **Automatic Switching Circuit** utilizes both the input and output of the NMOS inverter to toggle the states of two different audio power amplifiers. The LM4880 is used to drive stereo single ended loads, while the LM4861 drives bridged internal speakers.

In this application, the LM4880 and LM4861 are never on at the same time. When the switch inside the headphone jack is open, the LM4880 is enabled and the LM4861 is disabled since the NMOS inverter is on. If a headphone jack is not present, it is assumed that the internal speakers should be on and thus the voltage on the LM4861 shutdown pin is low and the voltage at the LM4880 pin is high. This results in the LM4880 being shutdown and the LM4861 being enabled.

Only one channel of this circuit is shown in *Figure 3* to keep the drawing simple but the typical application would a

Application Information (Continued)

LM4880 driving a stereo external headphone jack and two LM4861's driving the internal stereo speakers. If only one internal speaker is required, a single LM4861 can be used as a summer to mix the left and right inputs into a single mono channel.

PROPER SELECTION OF EXTERNAL COMPONENTS

Selection of external components when using integrated power amplifiers is critical to optimize device and system performance. While the LM4880 is tolerant of external component combinations, care must be exercised when choosing component values.

The LM4880 is unity-gain stable which gives a designer maximum system flexibility. The LM4880 should be used in low gain configurations to minimize THD + N values, and maximize the signal to noise ratio. Low gain configurations require large input signals to obtain a given output power. Input signals equal to or greater than 1 Vrms are available from sources such as audio codecs. Please refer to the section, **Audio Power Amplifier Design,** for a more complete explanation of proper gain selection.

Besides gain, one of the major design considerations is the closed-loop bandwidth of the amplifier. To a large extent, the bandwidth is dictated by the choice of external components shown in *Figure 1.* Both the input coupling capacitor, C_i, and the output coupling capacitor, C_o, form first order high pass filters which limit low frequency response. These values should be chosen based on needed frequency response for a few distinct reasons.

Selection of Input and Output Capacitor Size

Large input and output capacitors are both expensive and space hungry for portable designs. Clearly a certain sized capacitor is needed to couple in low frequencies without severe attenuation. But in many cases the transducers used in portable systems, whether internal or external, have little ability to reproduce signals below 100 Hz–150 Hz. Thus using large input and output capacitors may not increase system performance.

In addition to system cost and size, click and pop performance is effected by the size of the input coupling capacitor, C_i. A larger input coupling capacitor requires more charge to reach its quiescent DC voltage (normally 1/2 V_{DD}.) This charge comes from the output via the feedback and is apt to create pops upon device enable. Thus, by minimizing the capacitor size based on necessary low frequency response, turn-on pops can be minimized.

Besides minimizing the input and output capacitor sizes, careful consideration should be paid to the bypass capacitor size. The bypass capacitor, C_B, is the most critical component to minimize turn-on pops since it determines how fast the LM4880 turns on. The slower the LM4880's outputs ramp to their quiescent DC voltage (nominally 1/2 V_{DD}), the smaller the turn-on pop. Choosing C_B equal to 1.0 µF along with a small value of C_i (in the range of 0.1 µF to 0.39 µF), should produce a virtually clickless and popless shutdown function. While the device will function properly, (no oscillations or motorboating), with C_B equal to 0.1 µF, the device will be much more susceptible to turn-on clicks and pops. Thus, a value of C_B equal to 1.0 µF or larger is recommended in all but the most cost sensitive designs.

AUDIO POWER AMPLIFIER DESIGN

Design a Dual 200 mW/8Ω Audio Amplifier

Given:

Power Output	200 mWrms
Load Impedance	8Ω
Input Level	1 Vrms (max)
Input Impedance	20 kΩ
Bandwidth	100 Hz–20 kHz ± 0.50 dB

A designer must first determine the needed supply rail to obtain the specified output power. Calculating the required supply rail involves knowing two parameters, V_{opeak} and also the dropout voltage. As shown in the Typical Performance Curves, the dropout voltage is typically 0.5V. V_{opeak} can be determined from Equation 3.

$$V_{opeak} = \sqrt{(2R_LP_o)}$$

For 200 mW of output power into an 8Ω load, the required V_{opeak} is 1.79V. Since this is a single supply application, the minimum supply voltage is twice the sum of V_{opeak} and V_{od}. Since 5V is a standard supply voltage in most applications, it is chosen for the supply rail. Extra supply voltage creates headroom that allows the LM4880 to reproduce peaks in excess of 200 mW without clipping the signal. At this time, the designer must make sure that the power supply choice along with the output impedance does not violate the conditions explained in the **Power Dissipation** section. Remember that the maximum power dissipation value from Equation 1 must be multiplied by two since there are two independent amplifiers inside the package.

Once the power dissipation equations have been addressed, the required gain can be determined from Equation 4.

$$|A_V| \geq \sqrt{(P_oR_L)}/(V_{IN}) = V_{orms}/V_{inrms} \quad (4)$$

$$A_V = -R_F/R_i \quad (5)$$

From Equation 4, the minimum gain is: $A_V = -1.26$

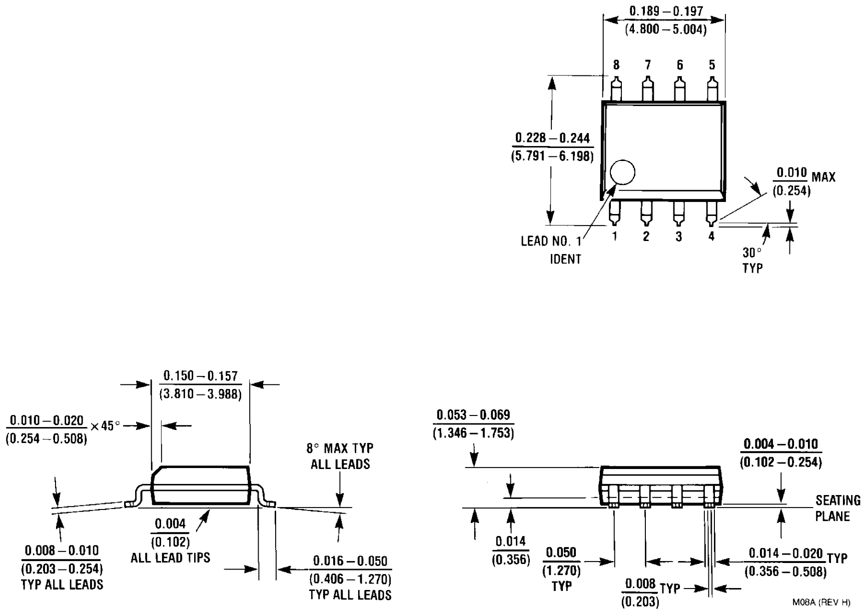
Since the desired input impedance was 20 kΩ, and with a gain of −1.26, a value of 27 kΩ is designated for R_f, assuming 5% tolerance resistors. This combination results in a nominal gain of −1.35. The final design step is to address the bandwidth requirements which must be stated as a pair of −3 dB frequency points. Five times away from a −3 dB point is 0.17 dB down from passband response assuming a single pole roll-off. As stated in the **External Components** section, both R_i in conjunction with C_i, and C_o with R_L, create first order high pass filters. Thus to obtain the desired frequency low response of 100 Hz within ± 0.5 dB, both poles must be taken into consideration. The combination of two single order filters at the same frequency forms a second order response. This results in a signal which is down 0.34 dB at five times away from the single order filter −3 dB point. Thus, a frequency of 20 Hz is used in the following equations to ensure that the response if better than 0.5 dB down at 100 Hz.

$$C_i \geq 1/(2\pi * 20k\Omega * 20Hz) = 0.397\ \mu F;\ \text{use } 0.39\ \mu F$$

$$C_o \geq 1/(2\pi * 8\Omega * 20Hz) = 995\ \mu F;\ \text{use } 1000\ \mu F$$

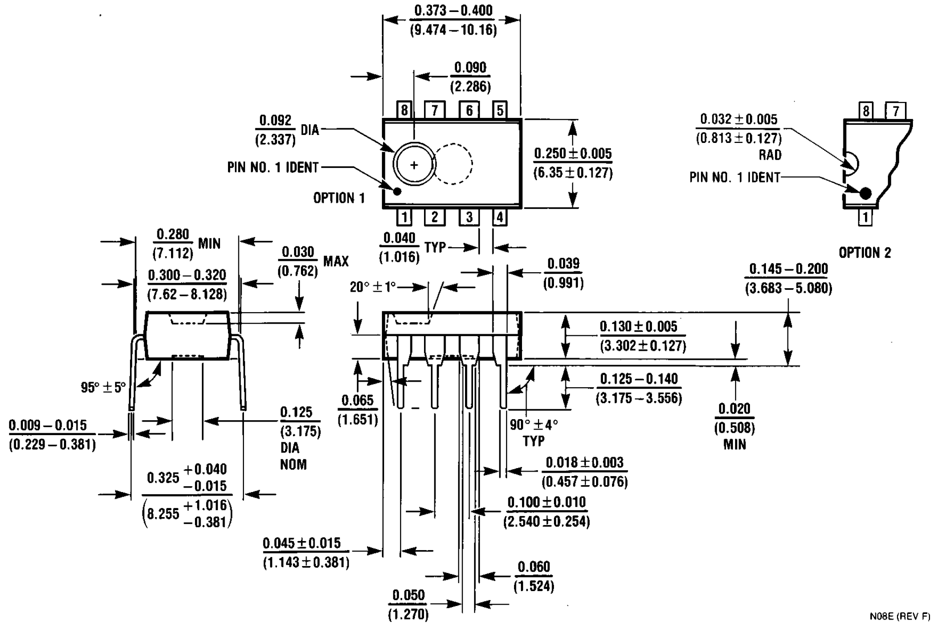
The high frequency pole is determined by the product of the desired high frequency pole, f_H, and the closed-loop gain, A_V. With a closed-loop gain magnitude of 1.35 and f_H = 100 kHz, the resulting GBWP = 135 kHz which is much smaller than the LM4880 GBWP of 12.5 MHz. This figure displays that if a designer has a need top design an amplifier with a higher gain, the LM4880 can still be used without running into bandwidth limitations.

Physical Dimensions inches (millimeters)



8-Lead (0.150″ Wide) Molded Small Outline Package, JEDEC
Order Number LM4880M
NS Package Number M08A

Physical Dimensions inches (millimeters) (Continued)



8-Lead (0.300″ Wide) Molded Dual-In-Line Package
Order Number LM4880N
NS Package Number N08E

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