July 2005

National Semiconductor

LM4938 Boomer® Audio Power Amplifier Series
Stereo 2W Audio Power Amplifiers with DC Volume Control and Selectable Gain

General Description

The LM4938 is a monolithic integrated circuit that provides DC volume control, and stereo bridged audio power amplifiers capable of producing 2W into 4Ω (Note 1) with less than 1.0% THD or 2.2W into 3Ω (Note 2) with less than 1.0% THD.

Boomer® audio integrated circuits were designed specifically to provide high quality audio while requiring a minimum amount of external components. The LM4938 incorporates a DC volume control, stereo bridged audio power amplifiers and a selectable gain or bass boost, making it optimally suited for multimedia monitors, portable radios, desktop, and portable computer applications.

The LM4938 features an externally controlled, low-power consumption shutdown mode, and both a power amplifier and headphone mute for maximum system flexibility and performance.

Note 1: When properly mounted to the circuit board, LM4938MH will deliver 2W into 4Ω. See **Application Information** section **Exposed-DAP package PCB Mounting Considerations** for more information.

Note 2: An LM4938MH that has been properly mounted to the circuit board and forced-air cooled will deliver 2.2W into 3Ω.

Key Specifications

- P_O at 1% THD+N
- into 3Ω — 2.2W (typ)
- into 4Ω — 2.0W (typ)
- into 8Ω — 1.3W (typ)
- Single-ended mode - THD+N at 92mW into 32Ω — 1.0%(typ)
- Shutdown current — 0.5µA (typ)

Features

- Improved click and pop circuitry virtually eliminates noise during turn on/off transitions
- DC Volume Control Interface
- System Beep Detect
- Stereo switchable bridged/single-ended power amplifiers
- Selectable internal/external gain and bass boost
- Thermal shutdown protection circuitry
- Unity gain stable

Applications

- Flat Panel Displays
- Portable and Desktop Computers
- Multimedia Monitors
- Portable Radios, PDAs, and Portable TVs

Block Diagram

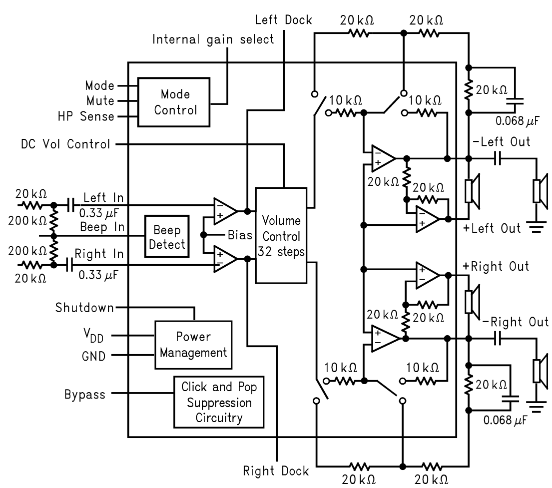

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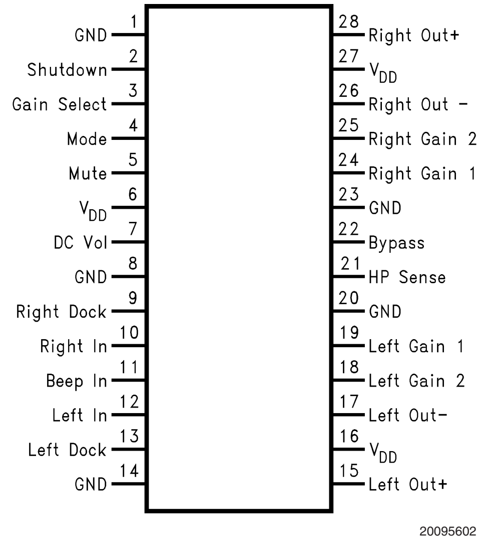
FIGURE 1. LM4938 Block Diagram

Connection Diagram

TSSOP Package



Top View
Order Number LM4938MH
See NS Package Number MXA28A for Exposed-DAP TSSOP

Absolute Maximum Ratings (Note 10)

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 11)	Internally limited
ESD Susceptibility (Note 12)	2000V
ESD Susceptibility (Note 13)	200V
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.

θ_{JC} (typ) - MXA28A	2˚C/W
θ_{JA} (typ) - MXA28A (exposed DAP) (Note 3)	41˚C/W
θ_{JA} (typ) - MXA28A (exposed DAP) (Note 4)	54˚C/W
θ_{JA} (typ) - MXA28A (exposed DAP) (Note 5)	59˚C/W
θ_{JA} (typ) - MXA28A (exposed DAP) (Note 6)	93˚C/W

Operating Ratings

Temperature Range	
$T_{MIN} \leq T_A \leq T_{MAX}$	–20˚C ≤TA ≤ 85˚C
Supply Voltage	2.7V≤ V_{DD} ≤ 5.5V

Electrical Characteristics for Entire IC (Notes 7, 10)

The following specifications apply for V_{DD} = 5V unless otherwise noted. Limits apply for T_A = 25˚C.

Symbol	Parameter	Conditions	LM4938		Units (Limits)
			Typical (Note 14)	Limit (Note 15)	
V_{DD}	Supply Voltage			2.7	V (min)
				5.5	V (max)
I_{DD}	Quiescent Power Supply Current	V_{IN} = 0V, I_O = 0A	11	30	mA (max)
I_{SD}	Shutdown Current	$V_{shutdown}$ = V_{DD}	0.5	2.0	µA (max)
V_{IH}	Headphone Sense High Input Voltage			4	V (min)
V_{IL}	Headphone Sense Low Input Voltage			0.8	V (max)

Electrical Characteristics for Volume Attenuators (Notes 7, 10)

The following specifications apply for V_{DD} = 5V. Limits apply for T_A = 25˚C.

Symbol	Parameter	Conditions	LM4938		Units (Limits)
			Typical (Note 14)	Limit (Note 15)	
C_{RANGE}	Attenuator Range	Gain accuracy with V_{DCVol} = 5V, No Load	±0.5	±0.75	dB (max)
		Gain accuracy with V_{DCVol} < 0.5V, No Load	±2		dB (max)
		Attenuation with V_{DCVol} = 0V (BM & SE)	89	75	dB (min)
A_M	Mute Attenuation	V_{mute} = 5V, Bridged Mode (BM)	89	78	dB (min)
		V_{mute} = 5V, Single-Ended Mode (SE)		78	dB (min)

Electrical Characteristics for Bridged Mode Operation (Notes 7, 10)

The following specifications apply for V_{DD} = 5V, unless otherwise noted. Limits apply for T_A = 25˚C.

Symbol	Parameter	Conditions	LM4938		Units (Limits)
			Typical (Note 14)	Limit (Note 15)	
V_{OS}	Output Offset Voltage	V_{IN} = 0V, No Load	5	±50	mV (max)

Electrical Characteristics for Bridged Mode Operation (Notes 7, 10) (Continued)

The following specifications apply for V_{DD} = 5V, unless otherwise noted. Limits apply for T_A = 25˚C.

Symbol	Parameter	Conditions	LM4938		Units (Limits)
			Typical (Note 14)	Limit (Note 15)	
P_O	Output Power	THD + N = 1.0%; f = 1kHz R_L = 3Ω (Note 8)	2.2		W
		THD + N = 1.0%; f = 1kHz R_L = 4Ω (Note 9)	2		W
		THD = 1% (max); f = 1kHz R_L = 8Ω	1.3	1.0	W (min)
		THD+N = 10%; f = 1 kHz; R_L = 8Ω	1.5		W
THD+N	Total Harmonic Distortion + Noise	P_O = 0.4W, f = 1kHz, R_L = 8Ω, A_{VD} = 2	0.05		%
PSRR	Power Supply Rejection Ratio	C_B = 1.0 µF, f = 120 Hz, V_{RIPPLE} = 200 mVrms; R_L = 8Ω, Floating	78		dB
		C_B = 1.0 µF, f = 120 Hz, V_{RIPPLE} = 200 mVrms; R_L = 8Ω, Terminated	60		dB
SNR	Signal to Noise Ratio	V_{DD} = 5V, P_{OUT} = 1.2W, R_L = 8Ω, A-Wtd Filter, 1kHz	100		dB
X_{talk}	Channel Separation	f = 1kHz, C_B = 1.0µF, 1W	76		dB

Electrical Characteristics for Single-Ended Mode Operation (Notes 7, 10)

The following specifications apply for V_{DD} = 5V. Limits apply for T_A = 25˚C.

Symbol	Parameter	Conditions	LM4938		Units (Limits)
			Typical (Note 14)	Limit (Note 15)	
P_O	Output Power	THD = 1.0%; f = 1kHz; R_L = 32Ω	92		mW
THD+N	Total Harmonic Distortion + Noise	V_{OUT} = 1V_{RMS}, f = 1kHz, R_L = 10kΩ, A_{VD} = 1	0.065		%
PSRR	Power Supply Rejection Ratio	C_B = 1.0 µF, f = 120 Hz, V_{RIPPLE} = 200 mVrms, Floating	63		dB
		C_B = 1.0 µF, f = 120 Hz, V_{RIPPLE} = 200 mVrms, Terminated	59		dB
SNR	Signal to Noise Ratio	P_{OUT} = 75mW, R_L = 32Ω, A-Wtd Filter	100		dB
X_{talk}	Channel Separation	f = 1kHz, C_B = 1.0 µF	73		dB

Electrical Characteristics for Single-Ended Mode Operation (Notes 7, 10) (Continued)

Note 3: The θ_{JA} given is for an MXA28A package whose exposed-DAP is soldered to an exposed 2in ^{2} piece of 1 ounce printed circuit board copper.

Note 4: The θ_{JA} given is for an MXA28A package whose exposed-DAP is soldered to a 2in^2 piece of 1 ounce printed circuit board copper on a bottom side layer through 21 8mil vias.

Note 5: The θ_{JA} given is for an MXA28A package whose exposed-DAP is soldered to an exposed 1in ^{2} piece of 1 ounce printed circuit board copper.

Note 6: The θ_{JA} given is for an MXA28A package whose exposed-DAP is not soldered to any copper.

Note 7: All voltages are measured with respect to the ground pins, unless otherwise specified. All specifications are tested using the typical application as shown in *Figure 1*.

Note 8: When driving 3Ω loads from a 5V supply the LM4938MH must be mounted to the circuit board and forced-air cooled.

Note 9: When driving 4Ω loads from a 5V supply the LM4938MH must be mounted to the circuit board.

Note 10: *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 11: 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 $P_{DMAX} = (T_{JMAX} – T_A)/\theta_{JA}$. For the LM4938, T_{JMAX} = 150˚C, and the typical junction-to-ambient thermal resistance for each package can be found in the **Absolute Maximum Ratings** section above.

Note 12: Human body model, 100pF discharged through a 1.5kΩ resistor.

Note 13: Machine Model, 200pF – 220pF discharged through all pins.

Note 14: Typicals are measured at 25˚C and represent the parametric norm.

Note 15: Limits are guaranteed to National's AOQL (Average Outgoing Quality Level). Datasheet min/max specification limits are guaranteed by design, test, or statistical analysis.

Typical Application

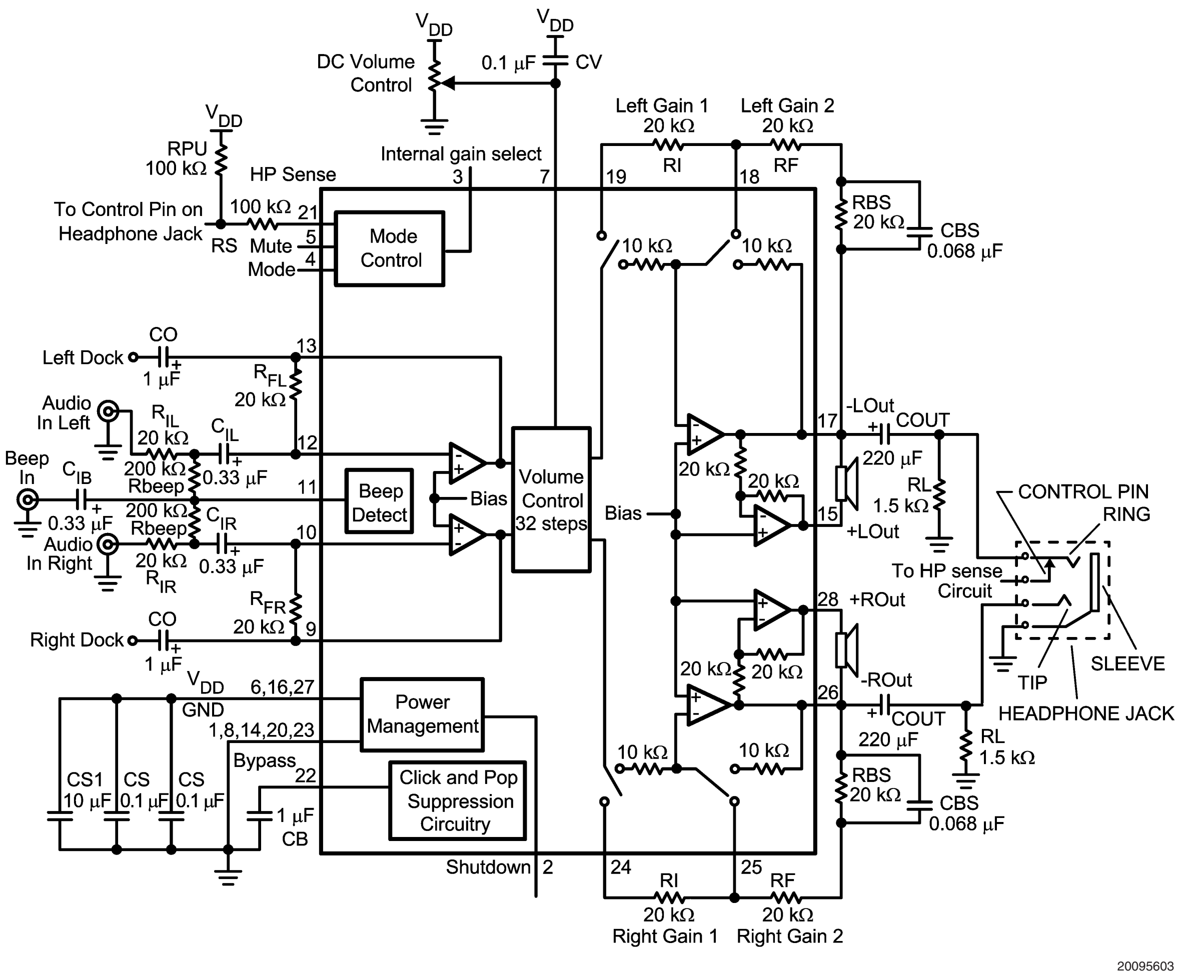


FIGURE 2. Typical Application Circuit

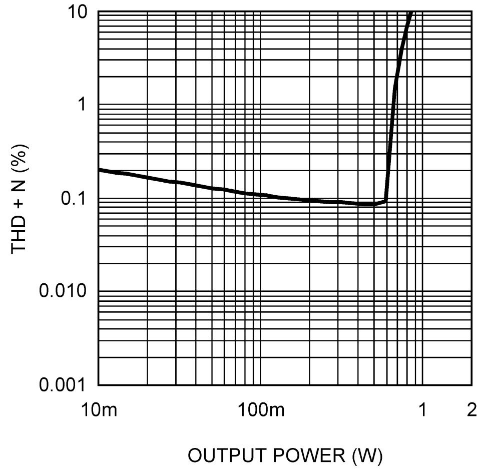
Truth Table for Logic Inputs (Note 16)

Gain Sel	Mode	Headphone Sense	Mute	Shutdown	Output Stage Set To	DC Volume	Output Stage Configuration
0	0	0	0	0	Internal Gain	Fixed	BTL
0	0	1	0	0	Internal Gain	Fixed	SE
0	1	0	0	0	Internal Gain	Adjustable	BTL
0	1	1	0	0	Internal Gain	Adjustable	SE
1	0	0	0	0	External Gain	Fixed	BTL
1	0	1	0	0	External Gain	Fixed	SE
1	1	0	0	0	External Gain	Adjustable	BTL
1	1	1	0	0	External Gain	Adjustable	SE
X	X	X	1	0	Muted	X	Muted
X	X	X	X	1	Shutdown	X	X

Note 16: If system beep is detected on the Beep In pin, the system beep will be passed through the bridged amplifier regardless of the logic of the Mute and HP sense pins.

Typical Performance Characteristics

THD+N vs Output Power
V_{DD} = 3V, R_L = 4Ω, f = 1kHz



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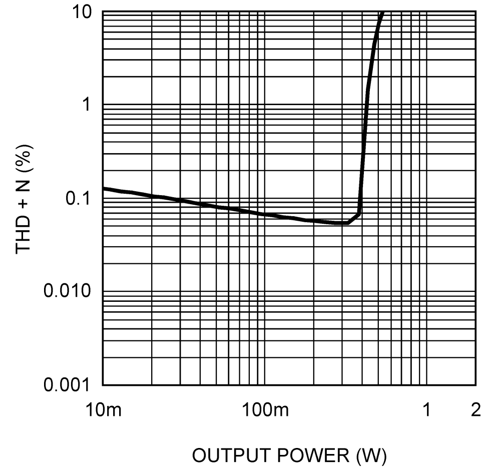
THD+N vs Output Power
V_{DD} = 3V, R_L = 8Ω, f = 1kHz



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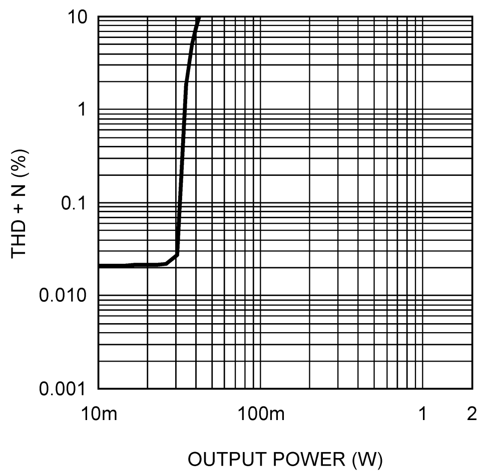
THD+N vs Output Power
V_{DD} = 3V, R_L = 32Ω, SE, f = 1kHz



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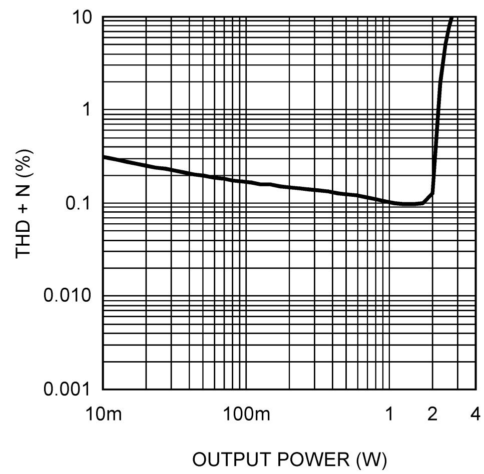
THD+N vs Output Power
V_{DD} = 5V, R_L = 3Ω, f = 1kHz



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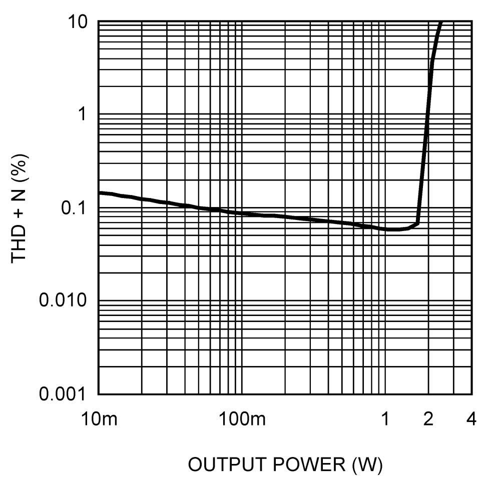
THD+N vs Output Power
V_{DD} = 5V, R_L = 4Ω, f = 1kHz



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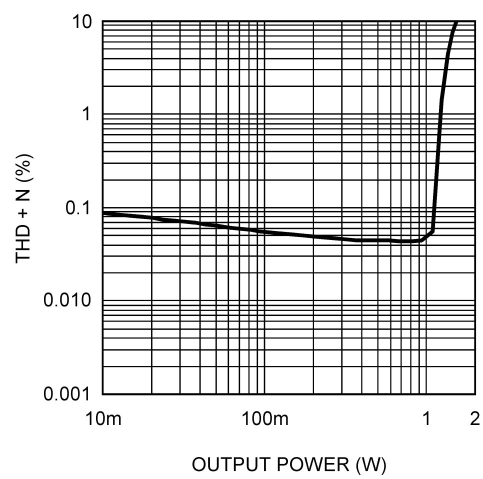
THD+N vs Output Power
V_{DD} = 5V, R_L = 8Ω, BTL, f = 1kHz



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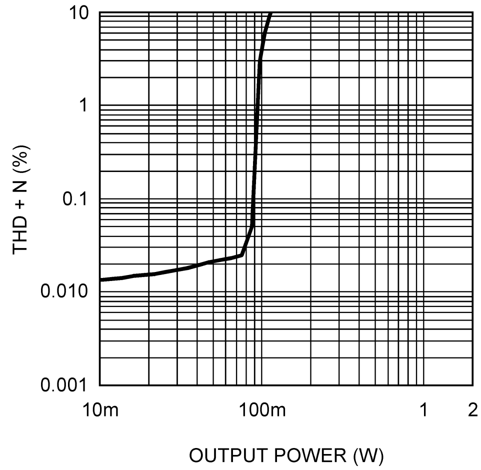
Typical Performance Characteristics (Continued)

THD+N vs Output Power
V_{DD} = 5V, R_L = 32Ω, SE, f = 1kHz



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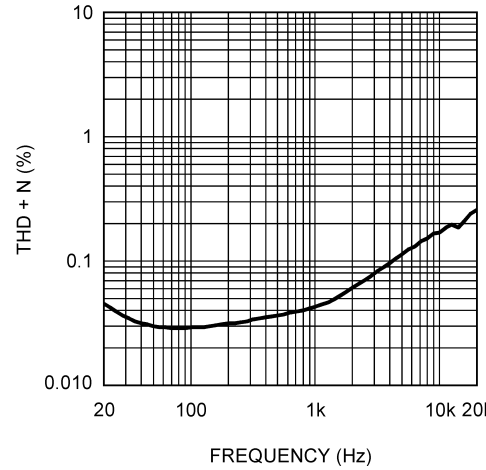
THD+N vs Frequency
V_{DD} = 5V, R_L = 8Ω, P_O = 1W, BTL



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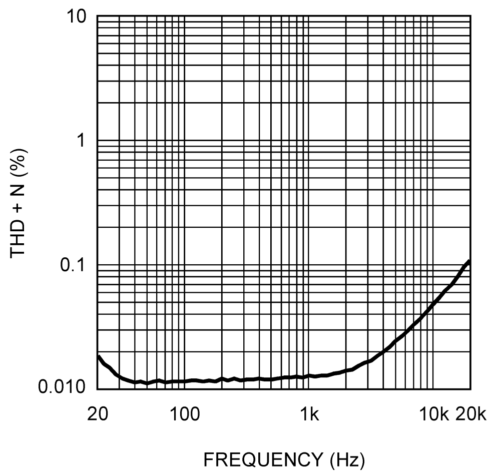
THD+N vs Frequency
V_{DD} = 3V, R_L = 4Ω, P_O = 170mW



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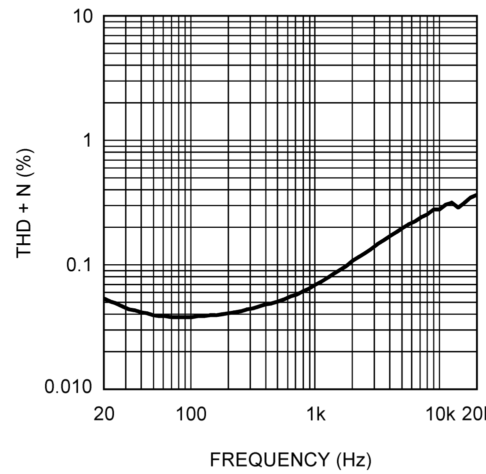
THD+N vs Frequency
V_{DD} = 3V, R_L = 8Ω, P_O = 160mW



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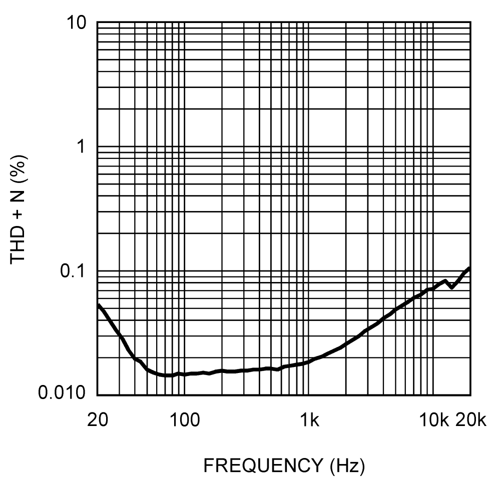
THD+N vs Frequency
V_{DD} = 3V, R_L = 32Ω, P_O = 20mW, SE



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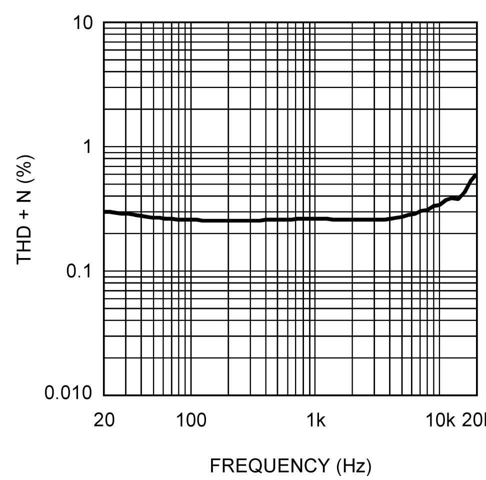
THD+N vs Frequency
V_{DD} = 5V, R_L = 3Ω, P_O = 600mW



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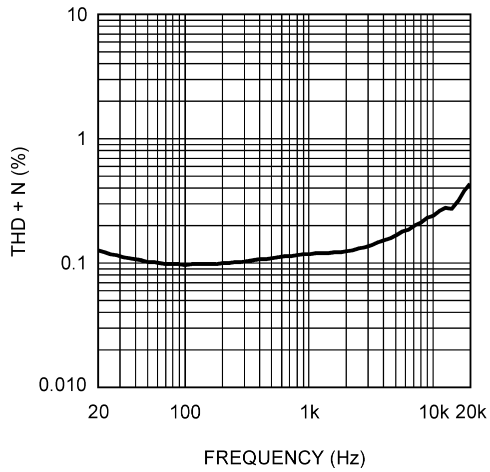
Typical Performance Characteristics (Continued)

THD+N vs Frequency
V_{DD} = 5V, R_L = 4Ω, P_O = 600mW



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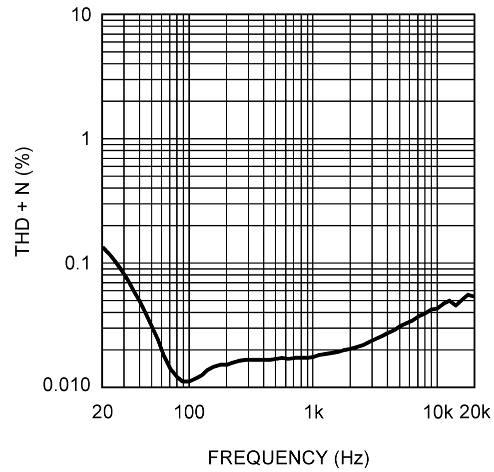
THD+N vs Frequency
V_{DD} = 5V, R_L = 32Ω, P_O = 70mW, SE



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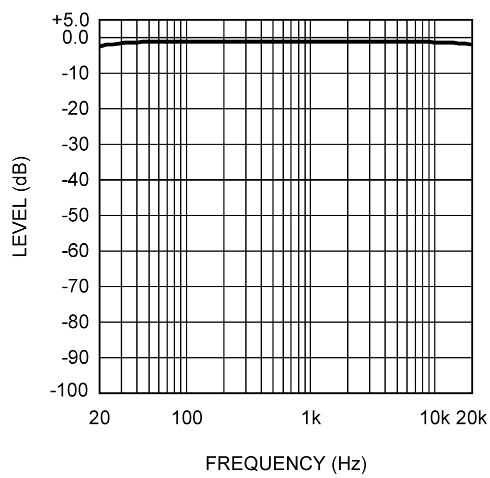
Frequency Response
V_{DD} = 3V, R_L = 4Ω, P_O = 1.8W



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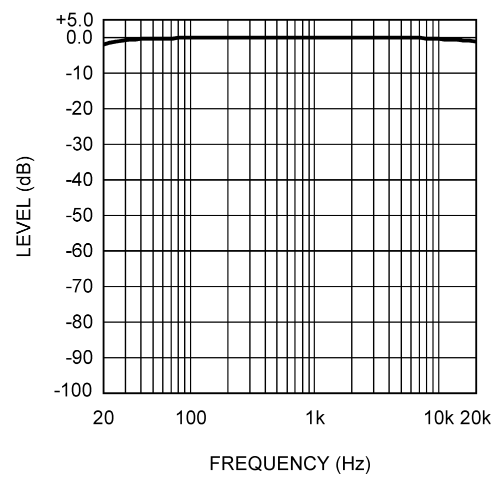
Frequency Response
V_{DD} = 3V, R_L = 8Ω, P_O = 570mW



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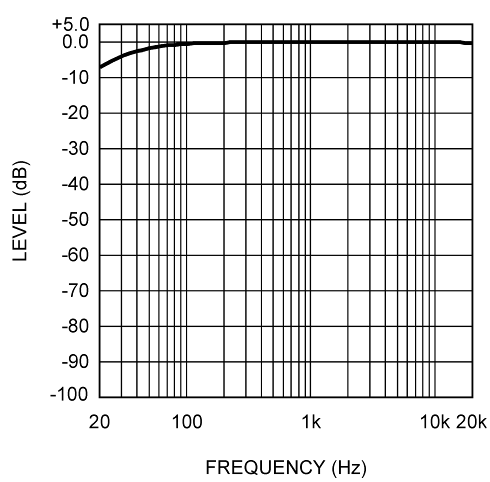
Frequency Response
V_{DD} = 3V, R_L = 32Ω, P_O = 30mW, SE



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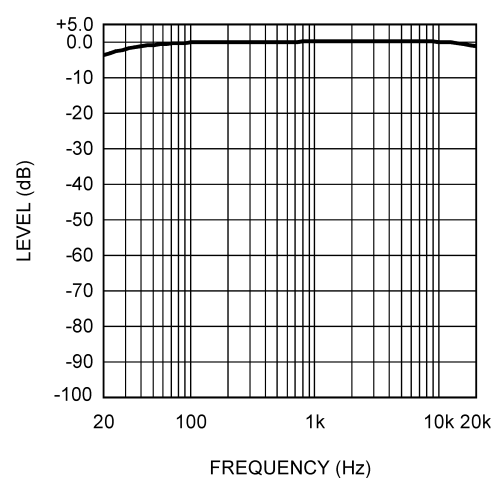
Frequency Response
V_{DD} = 5V, R_L = 3Ω, P_O = 1.8W



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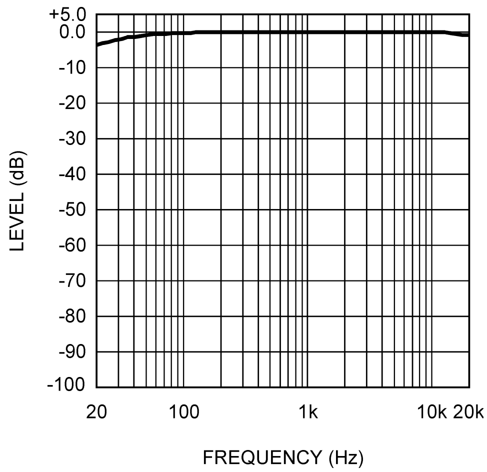
Typical Performance Characteristics (Continued)

Frequency Response
V_{DD} = 5V, R_L = 4Ω, P_O = 1.5W



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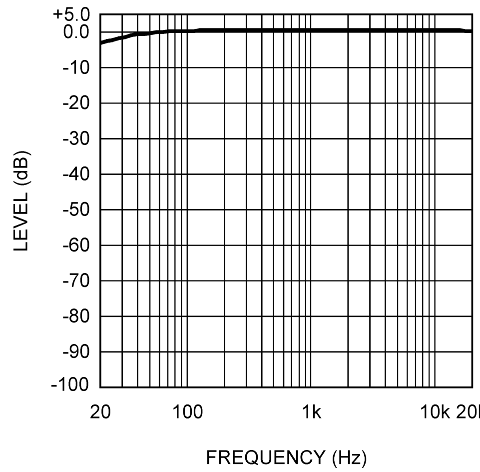
Frequency Response
V_{DD} = 5V, R_L = 8Ω, P_O = 1W



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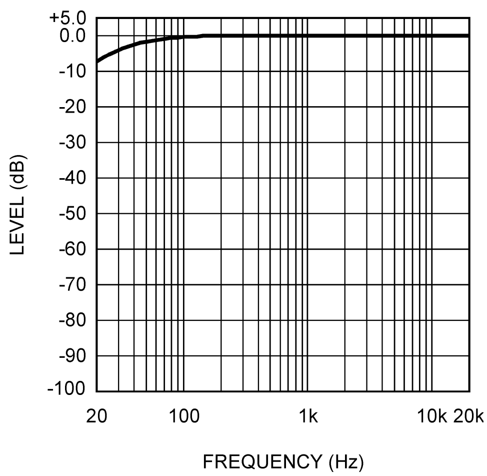
Frequency Response
V_{DD} = 5V, R_L = 32Ω, P_O = 30mW, SE



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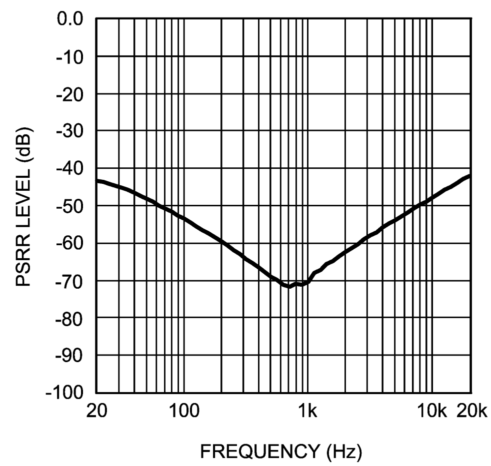
PSRR vs Frequency
V_{DD} = 3V, R_L = 8Ω, Terminated



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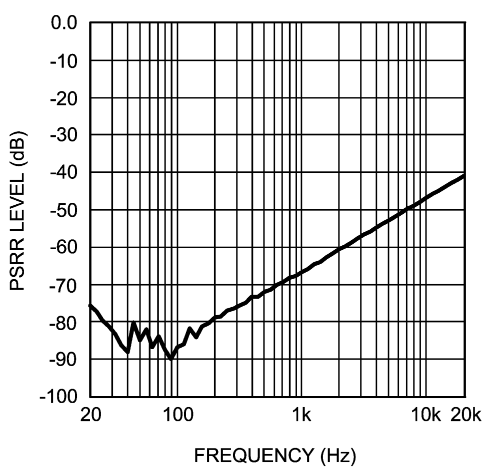
PSRR vs Frequency
V_{DD} = 3V, R_L = 8Ω, Unterminated



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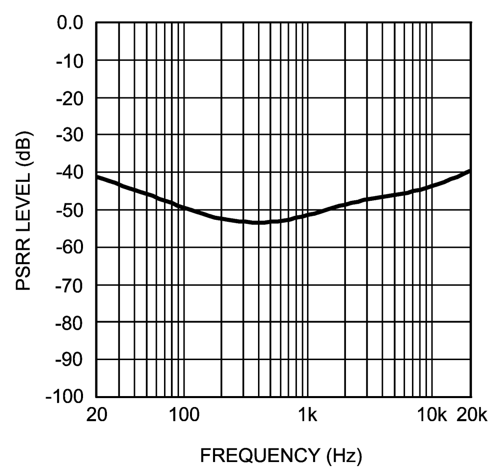
PSRR vs Frequency
V_{DD} = 3V, R_L = 32Ω, Terminated



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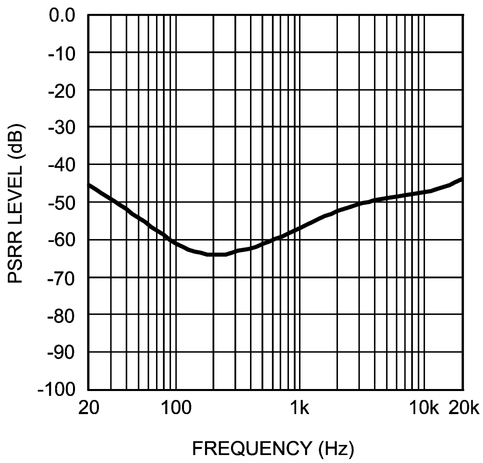
Typical Performance Characteristics (Continued)

PSRR vs Frequency
V_{DD} = 3V, R_L = 32Ω, Unterminated



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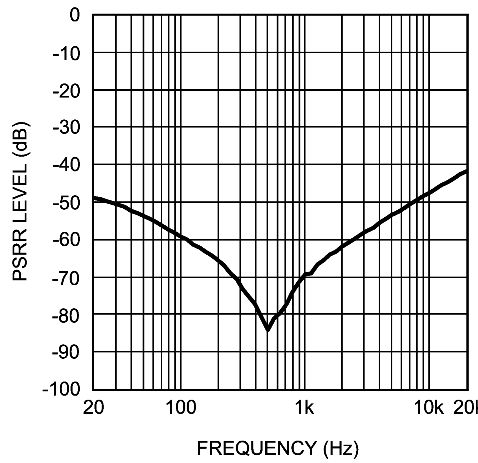
PSRR vs Frequency
V_{DD} = 5V, R_L = 8Ω, Terminated



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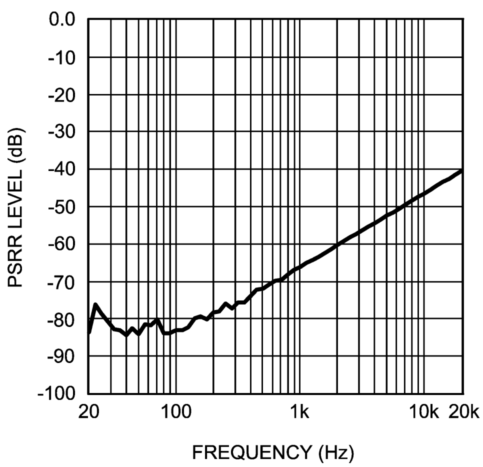
PSRR vs Frequency
V_{DD} = 5V, R_L = 8Ω, Unterminated



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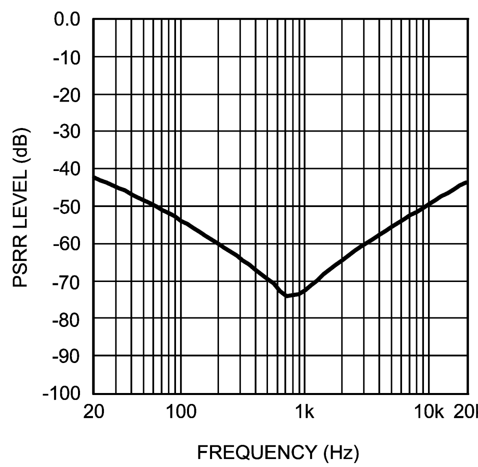
PSRR vs Frequency
V_{DD} = 5V, R_L = 32Ω, Terminated, SE



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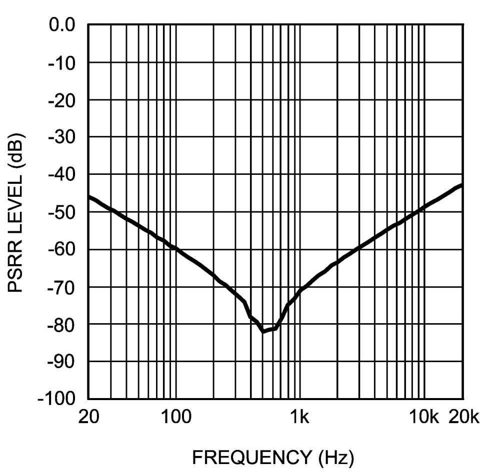
PSRR vs Frequency
V_{DD} = 5V, R_L = 32Ω, Unterminated, SE



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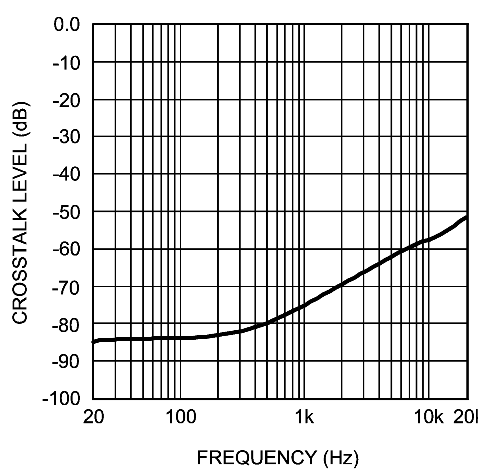
Crosstalk vs Frequency
V_{DD} = 3V, R_L = 8Ω, P_O = 570mW



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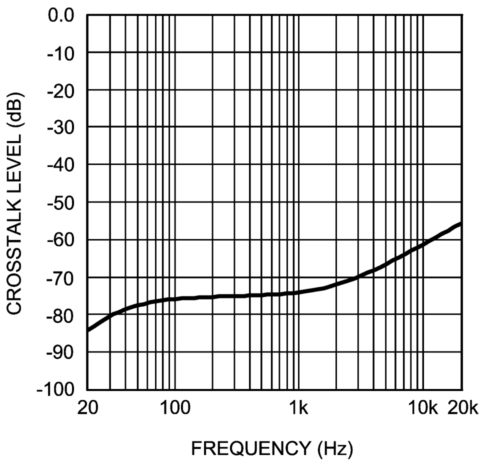
Typical Performance Characteristics (Continued)

Crosstalk vs Frequency
V_{DD} = 3V, R_L = 32Ω, P_O = 30mW, SE



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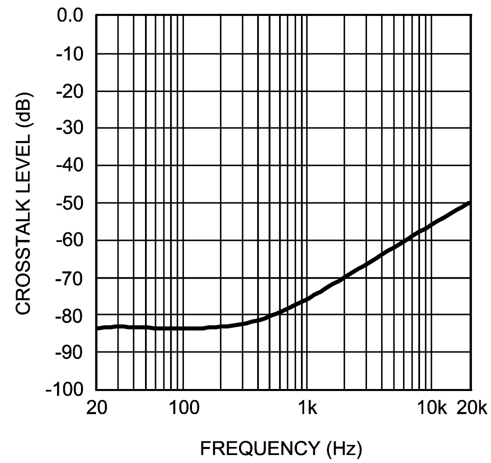
Crosstalk vs Frequency
V_{DD} = 5V, R_L = 8Ω, P_O = 1W



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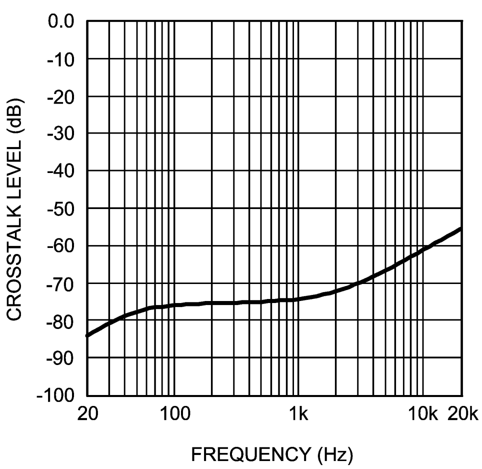
Crosstalk vs Frequency
V_{DD} = 5V, R_L = 32Ω, P_O = 30mW, SE



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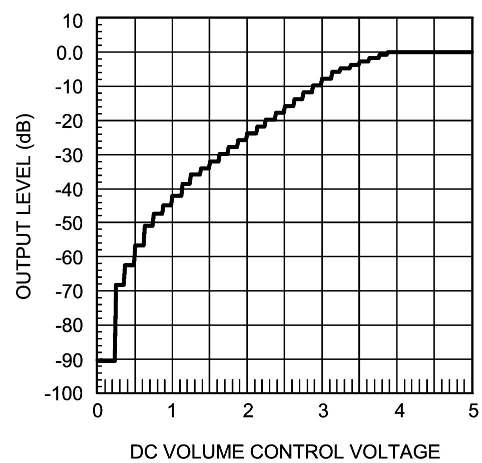
Volume Control Characteristics



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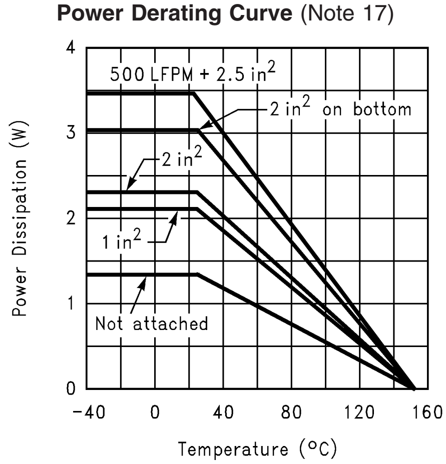
Power Derating Curve (Note 17)



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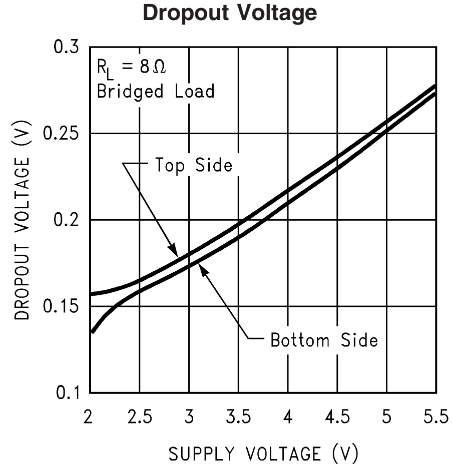
Dropout Voltage



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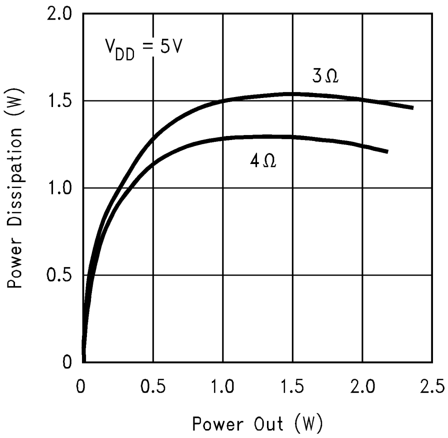
Typical Performance Characteristics (Continued)

Power Dissipation vs Output Power



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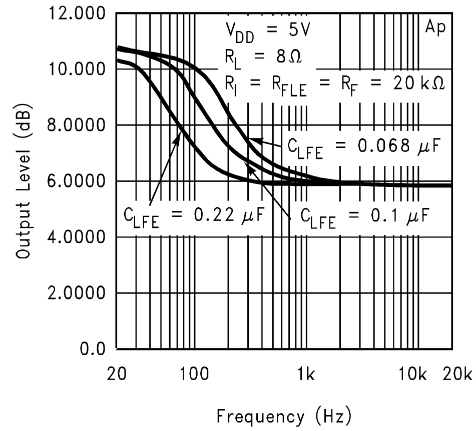
External Gain/ Bass Boost Characteristics



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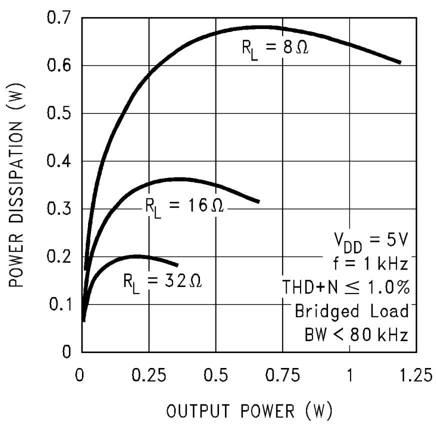
Power Dissipation vs Output Power



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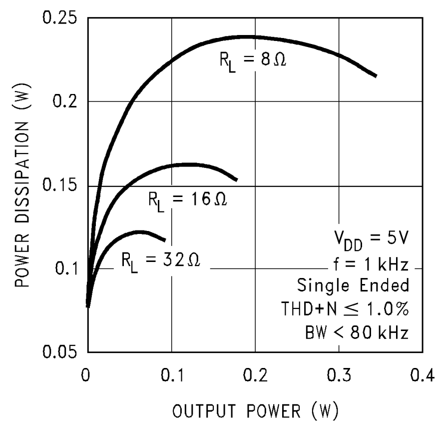
Power Dissipation vs Output Power



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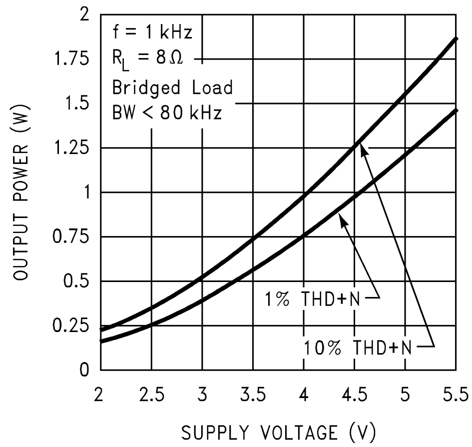
Typical Performance Characteristics (Continued)

Output Power vs Supply Voltage



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Note 17: These curves show the thermal dissipation ability of the LM4938MH at different ambient temperatures given these conditions:

500LFPM + 2in^2: The part is soldered to a 2in^2, 1 oz. copper plane with 500 linear feet per minute of forced-air flow across it.

2in^{2}on bottom: The part is soldered to a 2in^2, 1oz. copper plane that is on the bottom side of the PC board through 21 8 mil vias.

2in^2: The part is soldered to a 2in^2, 1oz. copper plane.

1in^2: The part is soldered to a 1in^2, 1oz. copper plane.

Not Attached: The part is not soldered down and is not forced-air cooled.

Application Information

EXPOSED-DAP PACKAGE PCB MOUNTING CONSIDERATIONS

The LM4938's exposed-DAP (die attach paddle) package (MH) provides a low thermal resistance between the die and the PCB to which the part is mounted and soldered. This allows rapid heat transfer from the die to the surrounding PCB copper traces, ground plane and, finally, surrounding air. The result is a low voltage audio power amplifier that produces 2.0W at ≤ 1% THD with a 4Ω load. This high power is achieved through careful consideration of necessary thermal design. Failing to optimize thermal design may compromise the LM4938's high power performance and activate unwanted, though necessary, thermal shutdown protection.

The MH package must have its exposed DAP soldered to a grounded copper pad on the PCB. The DAP's PCB copper pad is connected to a large grounded plane of continuous unbroken copper. This plane forms a thermal mass heat sink and radiation area. Place the heat sink area on either outside plane in the case of a two-sided PCB, or on an inner layer of a board with more than two layers. Connect the DAP copper pad to the inner layer or backside copper heat sink area with 32(4x8) (MH) vias. The via diameter should be 0.012in–0.013in with a 1.27mm pitch. Ensure efficient thermal conductivity by plating-through and solder-filling the vias.

Best thermal performance is achieved with the largest practical copper heat sink area. If the heatsink and amplifier share the same PCB layer, a nominal 2.5in^2 (min) area is necessary for 5V operation with a 4Ω load. Heatsink areas not placed on the same PCB layer as the LM4938 MH package should be 5in^2 (min) for the same supply voltage and load resistance. The last two area recommendations apply for 25˚C ambient temperature. Increase the area to compensate for ambient temperatures above 25˚C. In systems using cooling fans, the LM4938MH can take advantage of forced air cooling. With an air flow rate of 450 linear-feet per minute and a 2.5in^2 exposed copper or 5.0in^2 inner layer copper plane heatsink, the LM4938MH can continuously drive a 3Ω load to full power. In all circumstances and conditions, the junction temperature must be held below 150˚C to prevent activating the LM4938's thermal shutdown protection. The LM4938's power de-rating curve in the **Typical Performance Characteristics** shows the maximum power dissipation versus temperature. Example PCB layouts for the exposed-DAP TSSOP are shown in the **Demonstration Board Layout** section. Further detailed and specific information concerning PCB layout, fabrication, and mounting a package is available in National Semiconductor's AN1187.

PCB LAYOUT AND SUPPLY REGULATION CONSIDERATIONS FOR DRIVING 3Ω AND 4Ω LOADS

Power dissipated by a load is a function of the voltage swing across the load and the load's impedance. As load impedance decreases, load dissipation becomes increasingly dependent on the interconnect (PCB trace and wire) resistance between the amplifier output pins and the load's connections. Residual trace resistance causes a voltage drop, which results in power dissipated in the trace and not in the load as desired. For example, 0.1Ω trace resistance reduces the output power dissipated by a 4Ω load from 2.1W to 2.0W. This problem of decreased load dissipation is exacerbated as load impedance decreases. Therefore, to maintain the highest load dissipation and widest output voltage swing, PCB traces that connect the output pins to a load must be as wide as possible.

Poor power supply regulation adversely affects maximum output power. A poorly regulated supply's output voltage decreases with increasing load current. Reduced supply voltage causes decreased headroom, output signal clipping, and reduced output power. Even with tightly regulated supplies, trace resistance creates the same effects as poor supply regulation. Therefore, making the power supply traces as wide as possible helps maintain full output voltage swing.

BRIDGE CONFIGURATION EXPLANATION

As shown in *Figure 2*, the LM4938 output stage consists of two pairs of operational amplifiers, forming a two-channel (channel A and channel B) stereo amplifier. (Though the following discusses channel A, it applies equally to channel B.)

Figure 2 shows that the first amplifier's negative (-) output serves as the second amplifier's input. This results in both amplifiers producing signals identical in magnitude, but 180˚ out of phase. Taking advantage of this phase difference, a load is placed between −OUTA and +OUTA and driven differentially (commonly referred to as "bridge mode"). This results in a differential gain of

$$A_{VD} = 2 * (R_f/R_i) \tag{1}$$

Bridge mode amplifiers are different from single-ended amplifiers that drive loads connected between a single amplifier's output and ground. For a given supply voltage, bridge mode has a distinct advantage over the single-ended configuration: **its differential output doubles the voltage swing across the load.** This produces four times the output power when 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 that the output signal is not clipped. To ensure minimum output signal clipping when choosing an amplifier's closed-loop gain, refer to the **Audio Power Amplifier Design** section.

Another advantage of the differential bridge output is no net DC voltage across the load. This is accomplished by biasing channel A's and channel B's outputs at half-supply. This eliminates the coupling capacitor that single supply, single-ended amplifiers require. Eliminating an output coupling capacitor in a single-ended configuration forces a single-supply amplifier's half-supply bias voltage across the load. This increases internal IC power dissipation and may permanently damage loads such as speakers.

POWER DISSIPATION

Power dissipation is a major concern when designing a successful single-ended or bridged amplifier. Equation (2) states the maximum power dissipation point for a single-ended amplifier operating at a given supply voltage and driving a specified output load.

$$P_{DMAX} = (V_{DD})^2/(2\pi^2 R_L) \quad \text{Single-Ended} \tag{2}$$

However, a direct consequence of the increased power delivered to the load by a bridge amplifier is higher internal power dissipation for the same conditions.

Application Information (Continued)

The LM4938 has two operational amplifiers per channel. The maximum internal power dissipation per channel operating in the bridge mode is four times that of a single-ended amplifier. From Equation (3), assuming a 5V power supply and a 4Ω load, the maximum single channel power dissipation is 1.27W or 2.54W for stereo operation.

$$P_{DMAX} = 4 * (V_{DD})^2/(2\pi^2 R_L) \quad \text{Bridge Mode} \qquad (3)$$

The LM4938's power dissipation is twice that given by Equation (2) or Equation (3) when operating in the single-ended mode or bridge mode, respectively. Twice the maximum power dissipation point given by Equation (3) must not exceed the power dissipation given by Equation (4):

$$P_{DMAX}' = (T_{JMAX} - T_A)/\theta_{JA} \qquad (4)$$

The LM4938's T_{JMAX} = 150˚C. In the MH package soldered to a DAP pad that expands to a copper area of 2in^2 on a PCB, the LM4938MH's θ_{JA} is 41˚C/W. At any given ambient temperature T_A, use Equation (4) to find the maximum internal power dissipation supported by the IC packaging. Rearranging Equation (4) and substituting P_{DMAX} for P_{DMAX}' results in Equation (5). This equation gives the maximum ambient temperature that still allows maximum stereo power dissipation without violating the LM4938's maximum junction temperature.

$$T_A = T_{JMAX} - 2*P_{DMAX}\ \theta_{JA} \qquad (5)$$

For a typical application with a 5V power supply and an 4Ω load, the maximum ambient temperature that allows maximum stereo power dissipation without exceeding the maximum junction temperature is approximately 45˚C for the MH package.

$$T_{JMAX} = P_{DMAX}\ \theta_{JA} + T_A \qquad (6)$$

Equation (6) gives the maximum junction temperature T_{JMAX}. If the result violates the LM4938's 150˚C T_{JMAX}, reduce the maximum junction temperature by reducing the power supply voltage or increasing the load resistance. Further allowance should be made for increased ambient temperatures.

The above examples assume that a device is a surface mount part operating around the maximum power dissipation point. Since internal power dissipation is a function of output power, higher ambient temperatures are allowed as output power or duty cycle decreases.

If the result of Equation (2) is greater than that of Equation (3), then decrease the supply voltage, increase the load impedance, or reduce the ambient temperature. If these measures are insufficient, a heat sink can be added to reduce θ_{JA}. The heat sink can be created using additional copper area around the package, with connections to the ground pin(s), supply pin and amplifier output pins. External, solder attached SMT heatsinks such as the Thermalloy 7106D can also improve power dissipation. When adding a heat sink, the θ_{JA} is the sum of θ_{JC}, θ_{CS}, and θ_{SA}. (θ_{JC} is the junction-to-case thermal impedance, θ_{CS} is the case-to-sink thermal impedance, and θ_{SA} is the sink-to-ambient thermal impedance.) Refer to the **Typical Performance Characteristics** curves for power dissipation information at lower output power levels.

POWER SUPPLY BYPASSING

As with any power amplifier, proper supply bypassing is critical for low noise performance and high power supply rejection. Applications that employ a 5V regulator typically use a 10 µF in parallel with a 0.1 µF filter capacitor to stabilize the regulator's output, reduce noise on the supply line, and improve the supply's transient response. However, their presence does not eliminate the need for a local 1.0µF tantalum bypass capacitance connected between the LM4938's supply pins and ground. Do not substitute a ceramic capacitor for the tantalum. Doing so may cause oscillation. Keep the length of leads and traces that connect capacitors between the LM4938's power supply pin and ground as short as possible. Connecting a 1µF capacitor, C_B, between the BYPASS pin and ground improves the internal bias voltage's stability and the amplifier's PSRR. The PSRR improvements increase as the BYPASS pin capacitor value increases. Too large a capacitor, however, increases turn-on time and can compromise the amplifier's click and pop performance. The selection of bypass capacitor values, especially C_B, depends on desired PSRR requirements, click and pop performance (as explained in the following section, **Selecting Proper External Components**), system cost, and size constraints.

SELECTING PROPER EXTERNAL COMPONENTS

Optimizing the LM4938's performance requires properly selecting external components. Though the LM4938 operates well when using external components with wide tolerances, best performance is achieved by optimizing component values.

The LM4938 is unity-gain stable, giving a designer maximum design flexibility. The gain should be set to no more than a given application requires. This allows the amplifier to achieve minimum THD+N and maximum signal-to-noise ratio. These parameters are compromised as the closed-loop gain increases. However, low gain circuits demand input signals with greater voltage swings to achieve maximum output power. Fortunately, many signal sources such as audio CODECs have outputs of $1V_{RMS}$ ($2.83V_{P-P}$). Please refer to the **Audio Power Amplifier Design** section for more information on selecting the proper gain.

INPUT CAPACITOR VALUE SELECTION

Amplifying the lowest audio frequencies requires a high value input coupling capacitor (0.33µF in *Figure 2*), but high value capacitors can be expensive and may compromise space efficiency in portable designs. In many cases, however, the speakers used in portable systems, whether internal or external, have little ability to reproduce signals below 150 Hz. Applications using speakers with this limited frequency response reap little improvement by using a large input capacitor.

Besides effecting system cost and size, the input coupling capacitor has an affect on the LM4938's click and pop performance. When the supply voltage is first applied, a transient (pop) is created as the charge on the input capacitor changes from zero to a quiescent state. The magnitude of the pop is directly proportional to the input capacitor's size. Higher value capacitors need more time to reach a quiescent DC voltage (usually $V_{DD}/2$) when charged with a fixed current. The amplifier's output charges the input capacitor

Application Information (Continued)

through the feedback resistor, R_f. Thus, pops can be minimized by selecting an input capacitor value that is no higher than necessary to meet the desired −6dB frequency.

As shown in *Figure 2*, the input resistor (R_{IR}, R_{IL} = 20k) (and the input capacitor (C_{IR}, C_{IL} = 0.33µF) produce a −6dB high pass filter cutoff frequency that is found using Equation (7).

$$f_{-6\,dB} = \frac{1}{2\pi R_{IN} C_1} \qquad (7)$$

As an example when using a speaker with a low frequency limit of 150Hz, the input coupling capacitor, using Equation (7), is 0.053µF. The 0.33µF input coupling capacitor shown in *Figure 2* allows the LM4938 to drive a high efficiency, full range speaker whose response extends below 30Hz.

OPTIMIZING CLICK AND POP REDUCTION PERFORMANCE

The LM4938 contains circuitry that minimizes turn-on and shutdown transients or “clicks and pops”. For this discussion, turn-on refers to either applying the power supply voltage or when the shutdown mode is deactivated. While the power supply is ramping to its final value, the LM4938’s internal amplifiers are configured as unity gain buffers. An internal current source changes the voltage of the BYPASS pin in a controlled, linear manner. Ideally, the input and outputs track the voltage applied to the BYPASS pin. The gain of the internal amplifiers remains unity until the voltage on the BYPASS pin reaches 1/2 V_{DD} . As soon as the voltage on the BYPASS pin is stable, the device becomes fully operational. Although the BYPASS pin current cannot be modified, changing the size of C_B alters the device’s turn-on time and the magnitude of “clicks and pops”. Increasing the value of C_B reduces the magnitude of turn-on pops. However, this presents a tradeoff: as the size of C_B increases, the turn-on time increases. There is a linear relationship between the size of C_B and the turn-on time.

DOCKING STATION INTERFACE

Applications such as notebook computers can take advantage of a docking station to connect to external devices such as monitors or audio/visual equipment that sends or receives line level signals. The LM4938 has two outputs, Right Dock and Left Dock, which connect to outputs of the internal input amplifiers that drive the volume control inputs. These input amplifiers can drive loads of >1kΩ (such as powered speakers) with a rail-to-rail signal. Since the output signal present on the RIGHT DOCK and LEFT DOCK pins is biased to V_{DD}/2, coupling capacitors should be connected in series with the load when using these outputs. Typical values for the output coupling capacitors are 0.33µF to 1.0µF. If polarized coupling capacitors are used, connect their "+" terminals to the respective output pin, see Figure 2.

Since the DOCK outputs precede the internal volume control, the signal amplitude will be equal to the input signal’s magnitude and cannot be adjusted. However, the input amplifier’s closed-loop gain can be adjusted using external resistors. These 20k resistors (R_{FR}, R_{FL}) are shown in *Figure 2* and they set each input amplifier’s gain to -1. Use Equation 7 to determine the input and feedback resistor values for a desired gain.

$$-A_{VR} = R_{FR}/R_{IR} \text{ and } -A_{VL} = R_{FL}/R_{IL} \qquad (8)$$

Adjusting the input amplifier’s gain sets the minimum gain for that channel. Although the single ended output of the Bridge Output Amplifiers can be used to drive line level outputs, it is recommended that the R & L Dock Outputs simpler signal path be used for better performance.

BEEP DETECT FUNCTION

Computers and notebooks produce a system “beep“ signal that drives a small speaker. The speaker’s auditory output signifies that the system requires user attention or input. To accommodate this system alert signal, the LM4938’s beep input pin is a mono input that accepts the beep signal. Internal level detection circuitry at this input monitors the beep signal’s magnitude. When a signal level greater than V_{DD}/2 is detected on the BEEP IN pin, the bridge output amplifiers are enabled. The beep signal is amplified and applied to the load connected to the output amplifiers. A valid beep signal will be applied to the load even when MUTE is active. Use the input resistors connected between the BEEP IN pin and the stereo input pins to accommodate different beep signal amplitudes. These resistors (R_{BEEP}) are shown as 200kΩ devices in *Figure 2*. Use higher value resistors to reduce the gain applied to the beep signal. The resistors must be used to pass the beep signal to the stereo inputs. The BEEP IN pin is used only to detect the beep signal’s magnitude: it does not pass the signal to the output amplifiers. The LM4938’s shutdown mode must be deactivated before a system alert signal is applied to BEEP IN pin.

If the “Beep” feature is not needed, remove the two Beep Resistors (200k) and Beep input capacitor (.33µf). Then, tie the Beep input pin (#11) to ground. Note that the Beep Circuit is designed to operate with only a square wave input from a control source.

Application Information (Continued)

MICRO-POWER SHUTDOWN

The voltage applied to the SHUTDOWN pin controls the LM4938's shutdown function. Activate micro-power shutdown by applying V_{DD} to the SHUTDOWN pin. When active, the LM4938's micro-power shutdown feature turns off the amplifier's bias circuitry, reducing the supply current. The logic threshold is typically $V_{DD}/2$. The low 0.5 µA typical shutdown current is achieved by applying a voltage that is as near as V_{DD} as possible to the SHUTDOWN pin. A voltage that is less than V_{DD} may increase the shutdown current.

There are a few ways to control the micro-power shutdown. These include using a single-pole, single-throw switch, a microprocessor, or a microcontroller. When using a switch, connect an external 10kΩ pull-up resistor between the SHUTDOWN pin and V_{DD}. Connect the switch between the SHUTDOWN pin and ground. Select normal amplifier operation by closing the switch. Opening the switch connects the SHUTDOWN pin to V_{DD} through the pull-up resistor, activating micro-power shutdown. The switch and resistor guarantee that the SHUTDOWN pin will not float. This prevents unwanted state changes. In a system with a microprocessor or a microcontroller, use a digital output to apply the control voltage to the SHUTDOWN pin. Driving the SHUTDOWN pin with active circuitry eliminates the need for a pull up resistor.

MODE FUNCTION

The LM4938's MODE function has 2 states controlled by the voltage applied to the MODE pin. Mode 0, selected by applying 0V to the MODE pin, forces the LM4938 to effectively function as a "line-out," unity-gain amplifier. Mode 1, which uses the internal DC controlled volume control is selected by applying V_{DD} to the MODE pin. This mode sets the amplifier's gain according to the DC voltage applied to the DC VOL CONTROL pin. Unanticipated gain behavior can be prevented by connecting the MODE pin to V_{DD} or ground. Note: Do not let the mode pin float.

MUTE FUNCTION

The LM4938 mutes the amplifier and DOCK outputs when V_{DD} is applied to the MUTE pin. Even while muted, the LM4938 will amplify a system alert (beep) signal whose magnitude satisfies the BEEP DETECT circuitry. Applying 0V to the MUTE pin returns the LM4938 to normal, unmuted operation. Prevent unanticipated mute behavior by connecting the MUTE pin to V_{DD} or ground. Do not let the mute pain float.

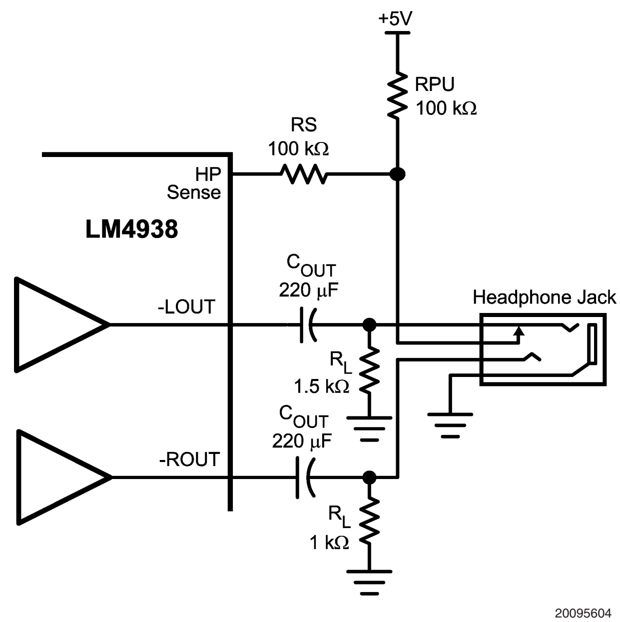

FIGURE 3. Headphone Sensing Circuit

HP SENSE FUNCTION (Head Phone In)

Applying a voltage between 4V and V_{DD} to the LM4938's HP-IN headphone control pin turns off the amps that drive the Left out "+" and Right out "+" pins. This action mutes a bridged-connected load. Quiescent current consumption is reduced when the IC is in this single-ended mode.

Figure 3 shows the implementation of the LM4938's headphone control function. With no headphones connected to the headphone jack, the R1-R2 voltage divider sets the voltage applied to the HP SENSE pin at approximately 50mV. This 50mV puts the LM4938 into bridged mode operation. The output coupling capacitor blocks the amplifier's half supply DC voltage, protecting the headphones.

The HP-IN threshold is set at 4V. While the LM4938 operates in bridged mode, the DC potential across the load is essentially 0V. Therefore, even in an ideal situation, the output swing cannot cause a false single-ended trigger. Connecting headphones to the headphone jack disconnects the headphone jack contact pin from R2 and allows R1 to pull the HP Sense pin up to V_{DD} through R4. This enables the headphone function, turns off both of the "+" output amplifiers, and mutes the bridged speaker. The remaining single-ended amplifiers then drive the headphones, whose impedance is in parallel with resistors R2 and R3. These resistors have negligible effect on the LM4938's output drive capability since the typical impedance of headphones is 32Ω.

Figure 3 also shows the suggested headphone jack electrical connections. The jack is designed to mate with a three-wire plug. The plug's tip and ring should each carry one of the two stereo output signals, whereas the sleeve should carry the ground return. A headphone jack with one control pin contact is sufficient to drive the HP-IN pin when connecting headphones.

A microprocessor or a switch can replace the headphone jack contact pin. When a microprocessor or switch applies a voltage greater than 4V to the HP-IN pin, a bridge-connected speaker is muted and the single ended output amplifiers 1A and 2A will drive a pair of headphones.

Application Information (Continued)

GAIN SELECT FUNCTION (Bass Boost)

The LM4938 features selectable gain, using either internal or external feedback resistors. Either set of feedback resistors set the gain of the output amplifiers. The voltage applied to the GAIN SELECT pin controls which gain is selected. Applying V_{DD} to the GAIN SELECT pin selects the external gain mode. Applying 0V to the GAIN SELECT pin selects the internally set unity gain.

In some cases a designer may want to improve the low frequency response of the bridged amplifier or incorporate a bass boost feature. This bass boost can be useful in systems where speakers are housed in small enclosures. A resistor, R_{LFE}, and a capacitor, C_{LFE}, in parallel, can be placed in series with the feedback resistor of the bridged amplifier as seen in Figure 4.

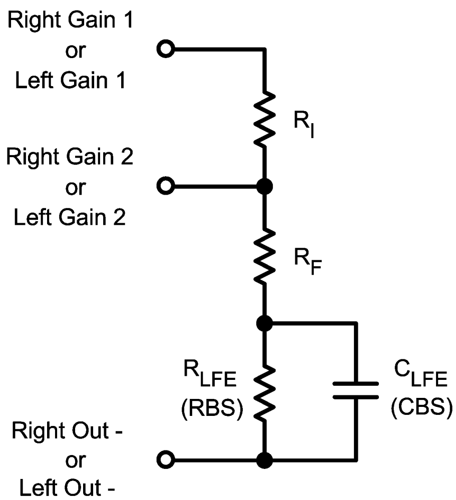

FIGURE 4. Low Frequency Enhancement

At low, frequencies C_{LFE} is a virtual open circuit and at high frequencies, its nearly zero ohm impedance shorts R_{LFE}. The result is increased bridge-amplifier gain at low frequencies. The combination of R_{LFE} and C_{LFE} form a -6dB corner frequency at

$$f_C = 1/(2\pi R_{LFE} C_{LFE}) \quad (9)$$

The bridged-amplifier low frequency differential gain is:

$$A_{VD} = 2(R_F + R_{LFE}) / R_i \quad (10)$$

Using the component values shown in *Figure 1* (R_F = 20kΩ, R_{LFE} = 20kΩ, and C_{LFE} = 0.068µF), a first-order, -6dB pole is created at 120Hz. Assuming R_i = 20kΩ, the low frequency differential gain is 4. The input (C_i) and output (C_O) capacitor values must be selected for a low frequency response that covers the range of frequencies affected by the desired bass-boost operation.

DC VOLUME CONTROL

The LM4938 has an internal stereo volume control whose setting is a function of the DC voltage applied to the DC VOL CONTROL pin.

The LM4938 volume control consists of 31 steps that are individually selected by a variable DC voltage level on the volume control pin. The range of the steps, controlled by the DC voltage, are from 0dB - 89dB. Each gain step corresponds to a specific input voltage range, as shown in table 2.

To minimize the effect of noise on the volume control pin, which can affect the selected gain level, hysteresis has been implemented. The amount of hysteresis corresponds to half of the step width, as shown in Volume Control Characterization Graph (DS200133-40).

For highest accuracy, the voltage shown in the 'recommended voltage' column of the table is used to select a desired gain. This recommended voltage is exactly halfway between the two nearest transitions to the next highest or next lowest gain levels.

The gain levels are 1dB/step from 0dB to -6dB, 2dB/step from -6dB to -36dB, 3dB/step from -36dB to -47dB, 4dB/step from -47db to -51dB, 5dB/step from -51dB to -66dB, and 12dB to the last step at -89dB.

Application Information (Continued)

VOLUME CONTROL TABLE (Table 2)

Gain (dB)	Voltage Range (% of Vdd)			Voltage Range (Vdd = 5)			Voltage Range (Vdd = 3)		
	Low	High	Recommended	Low	High	Recommended	Low	High	Recommended
0	77.5%	100.00%	100.000%	3.875	5.000	5.000	2.325	3.000	3.000
-1	75.0%	78.5%	76.875%	3.750	3.938	3.844	2.250	2.363	2.306
-2	72.5%	76.25%	74.375%	3.625	3.813	3.719	2.175	2.288	2.231
-3	70.0%	73.75%	71.875%	3.500	3.688	3.594	2.100	2.213	2.156
-4	67.5%	71.25%	69.375%	3.375	3.563	3.469	2.025	2.138	2.081
-5	65.0%	68.75%	66.875%	3.250	3.438	3.344	1.950	2.063	2.006
-6	62.5%	66.25%	64.375%	3.125	3.313	3.219	1.875	1.988	1.931
-8	60.0%	63.75%	61.875%	3.000	3.188	3.094	1.800	1.913	1.856
-10	57.5%	61.25%	59.375%	2.875	3.063	2.969	1.725	1.838	1.781
-12	55.0%	58.75%	56.875%	2.750	2.938	2.844	1.650	1.763	1.706
-14	52.5%	56.25%	54.375%	2.625	2.813	2.719	1.575	1.688	1.631
-16	50.0%	53.75%	51.875%	2.500	2.688	2.594	1.500	1.613	1.556
-18	47.5%	51.25%	49.375%	2.375	2.563	2.469	1.425	1.538	1.481
-20	45.0%	48.75%	46.875%	2.250	2.438	2.344	1.350	1.463	1.406
-22	42.5%	46.25%	44.375%	2.125	2.313	2.219	1.275	1.388	1.331
-24	40.0%	43.75%	41.875%	2.000	2.188	2.094	1.200	1.313	1.256
-26	37.5%	41.25%	39.375%	1.875	2.063	1.969	1.125	1.238	1.181
-28	35.0%	38.75%	36.875%	1.750	1.938	1.844	1.050	1.163	1.106
-30	32.5%	36.25%	34.375%	1.625	1.813	1.719	0.975	1.088	1.031
-32	30.0%	33.75%	31.875%	1.500	1.688	1.594	0.900	1.013	0.956
-34	27.5%	31.25%	29.375%	1.375	1.563	1.469	0.825	0.937	0.881
-36	25.0%	28.75%	26.875%	1.250	1.438	1.344	0.750	0.862	0.806
-39	22.5%	26.25%	24.375%	1.125	1.313	1.219	0.675	0.787	0.731
-42	20.0%	23.75%	21.875%	1.000	1.188	1.094	0.600	0.712	0.656
-45	17.5%	21.25%	19.375%	0.875	1.063	0.969	0.525	0.637	0.581
-47	15.0%	18.75%	16.875%	0.750	0.937	0.844	0.450	0.562	0.506
-51	12.5%	16.25%	14.375%	0.625	0.812	0.719	0.375	0.487	0.431
-56.5	10.0%	13.75%	11.875%	0.500	0.687	0.594	0.300	0.412	0.356
-62.5	7.5%	11.25%	9.375%	0.375	0.562	0.469	0.225	0.337	0.281
-68.5	5.0%	8.75%	6.875%	0.250	0.437	0.344	0.150	0.262	0.206
-89	0.0%	6.25%	0.000%	0.000	0.312	0.000	0.000	0.187	0.000

Application Information (Continued)

AUDIO POWER AMPLIFIER DESIGN

Audio Amplifier Design: Driving 1W into an 8Ω Load

The following are the desired operational parameters:

Power Output:	1 W_{RMS}
Load Impedance:	8Ω
Input Level:	1 V_{RMS}
Input Impedance:	20 kΩ
Bandwidth:	100 Hz–20 kHz ± 0.25 dB

The design begins by specifying the minimum supply voltage necessary to obtain the specified output power. One way to find the minimum supply voltage is to use the Output Power vs Supply Voltage curve in the **Typical Performance Characteristics** section. Another way, using Equation (10), is to calculate the peak output voltage necessary to achieve the desired output power for a given load impedance. To account for the amplifier's dropout voltage, two additional voltages, based on the Dropout Voltage vs Supply Voltage in the **Typical Performance Characteristics** curves, must be added to the result obtained by Equation (10). The result is Equation (11).

$$V_{outpeak} = \sqrt{(2R_L P_O)} \qquad (11)$$

$$V_{DD} \geq (V_{OUTPEAK} + (V_{OD_{TOP}} + V_{OD_{BOT}})) \qquad (12)$$

The Output Power vs Supply Voltage graph for an 8Ω load indicates a minimum supply voltage of 4.6V. This is easily met by the commonly used 5V supply voltage. The additional voltage creates the benefit of headroom, allowing the LM4938 to produce peak output power in excess of 1W without clipping or other audible distortion. The choice of supply voltage must also not create a situation that violates of maximum power dissipation as explained above in the **Power Dissipation** section.

After satisfying the LM4938's power dissipation requirements, the minimum differential gain needed to achieve 1W dissipation in an 8Ω load is found using Equation (12).

$$A_{VD} \geq \sqrt{(P_O R_L)}/(V_{IN}) = V_{orms}/V_{inrms} \qquad (13)$$

Thus, a minimum overall gain of 2.83 allows the LM4938's to reach full output swing and maintain low noise and THD+N performance.

The last step in this design example is setting the amplifier's −6dB frequency bandwidth. To achieve the desired ±0.25dB pass band magnitude variation limit, the low frequency response must extend to at least one-fifth the lower bandwidth limit and the high frequency response must extend to at least five times the upper bandwidth limit. The gain variation for both response limits is 0.17dB, well within the ±0.25dB desired limit. The results are an

$$f_L = 100Hz/5 = 20Hz \qquad (14)$$

and an

$$f_H = 20kHz \times 5 = 100kHz \qquad (15)$$

As mentioned in the **Selecting Proper External Components** section, R_i (Right & Left) and C_i (Right & Left) create a highpass filter that sets the amplifier's lower bandpass frequency limit. Find the input coupling capacitor's value using Equation (14).

$$C_i \geq 1/(2\pi R_i f_L) \qquad (16)$$

The result is

$$1/(2\pi * 20k\Omega * 20Hz) = 0.397\mu F \qquad (17)$$

Use a 0.39μF capacitor, the closest standard value.

The product of the desired high frequency cutoff (100kHz in this example) and the differential gain A_{VD}, determines the upper passband response limit. With A_{VD} = 3 and f_H = 100kHz, the closed-loop gain bandwidth product (GBWP) is 300kHz. This is less than the LM4938's 3.5MHz GBWP. With this margin, the amplifier can be used in designs that require more differential gain while avoiding performance,restricting bandwidth limitations.

Recommended Printed Circuit Board Layout

The following figures show the recommended PC board layouts for the LM4938MH. This circuit is designed for use with an external 5V supply and 4Ω speakers.

This circuit board is easy to use. Apply 5V and ground to the board's V_{DD} and GND pads, respectively. Connect 4Ω speakers between the board's −OUTA and +OUTA and OUTB and +OUTB pads.

Recommended Printed Circuit Board Layout (Continued)

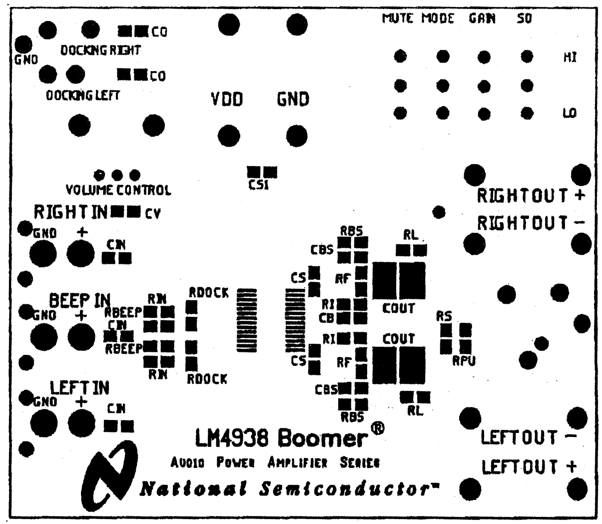

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FIGURE 5. Top Layer Silkscreen

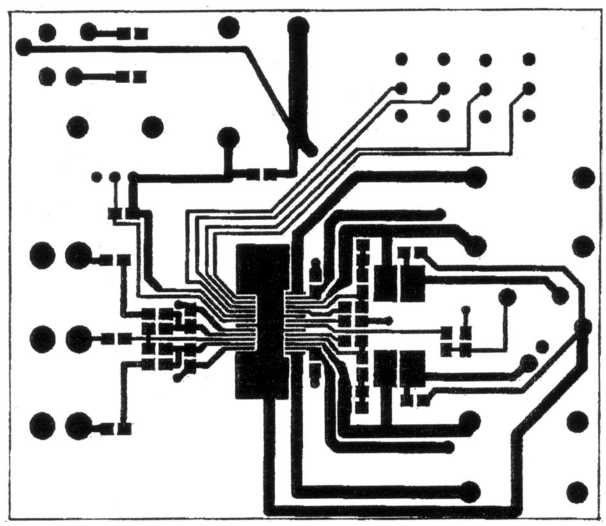

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FIGURE 6. Top Layer TSSOP

Recommended Printed Circuit Board Layout (Continued)

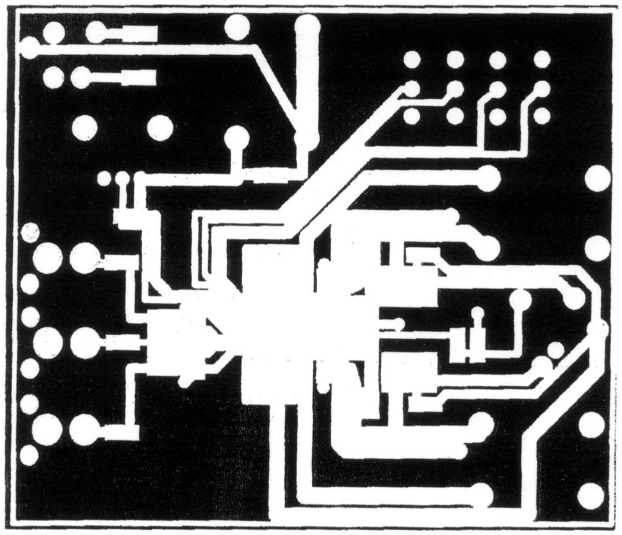

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FIGURE 7. Inner Layer (2)

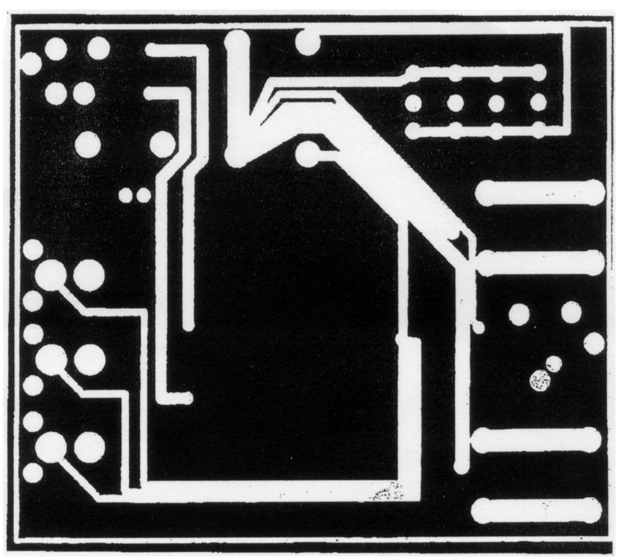

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FIGURE 8. Inner Layer (3)

Recommended Printed Circuit Board Layout (Continued)

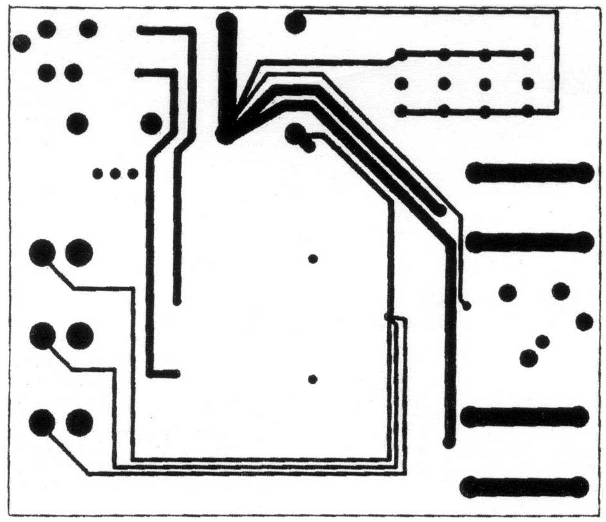

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FIGURE 9. Bottom Layer TSSOP

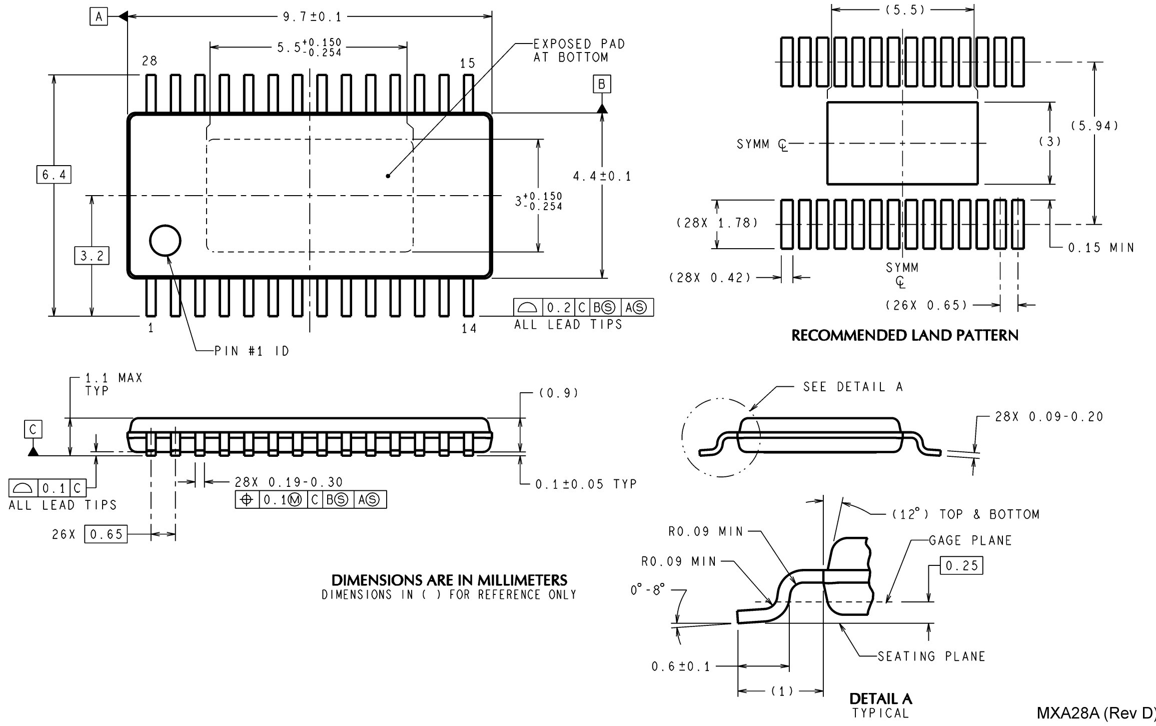
Analog Audio LM4938 TSSOP Eval Board
Assembly Part Number: 980011373-100
Revision: A
Bill of Material

Item	Part Number	Part Description	Qty	Ref Designator	Remark
1	551011373-001	LM4938 Eval Board PCB etch 001	1		
10	482911373-001	LM4938 TSSOP	1		
20	151911368-001	Cer Cap 0.068µF 50V 10% 1206	2	CBS	
25	152911368-001	Tant Cap 0.1µF 10V 10% Size = A 3216	3	CS, CS, CV	
26	152911368-002	Tant Cap 0.33µF 10V 10% Size = A 3216	3	CIN	
27	152911368-003	Tant Cap 1µF 16V 10% Size = A 3216	3	CB, CO1, CO2	
28	152911368-004	Tant Cap 10µF 10V 10% Size = C 6032	1	CS1	
29	152911368-005	Tant Cap 220µF 16V 10% Size = D 7343	2	CoutL, R	
30	472911368-001	Res 1.5K Ohm 1/8W 1% 1206	2	RL	
31	472911368-002	Res 20K Ohm 1/8W 1% 1206	10	RIN(4), RF(2), RDOCK(2), RBS(2)	
32	472911368-003	Res 100K Ohm 1/8W 1% 1206	2	RPU, RS	
33	472911368-004	Res 200K Ohm 1/16W 1% 0603	2	RBEEP	
40	131911368-001	Stereo Headphone Jack W/ Switch	1		Mouser # 161-3500
41	131911368-002	Slide Switch	4	mute, mode, Gain, SD	Mouser # 10SP003
42	131911368-003	Potentiometer	1	Volume Control	Mouser # 317-2090-100K
43	131911368-004	RCA Jack	3	Right-In, Beep-In, Left-In	Mouser # 16PJ097
44	131911368-005	Banana Jack, Black	3		Mouser # ME164-6219
45	131911368-006	Banana Jack, Red	3		Mouser # ME164-6218

Revision History

Rev	Date	Description
1.0	7/15/05	Added f = 1kHz to the titles on A2, A3, A4, A5, A6, A7, and A8. Re-released D/S to the WEB.

Physical Dimensions inches (millimeters) unless otherwise noted



Exposed-DAP TSSOP Package
Order Number LM4938MH
NS Package Number MXA28A for Exposed-DAP TSSOP

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