LME49720 Dual High Performance, High Fidelity Audio Operational Amplifier

1 Features

- Easily Drives 600Ω Loads
- Optimized for Superior Audio Signal Fidelity
- Output Short Circuit Protection
- PSRR and CMRR Exceed 120dB (typ)
- SOIC, PDIP, TO-99 Metal Can Packages
- Key Specifications
  - Power Supply Voltage Range: ±2.5 to ±17V
  - THD+N (A_V = 1, V_{OUT} = 3V_{RMS}, f_{IN} = 1kHz):
    - R_L = 2kΩ: 0.00003% (typ)
    - R_L = 600Ω: 0.00003% (typ)
  - Input Noise Density: 2.7nV/√Hz (typ)
  - Slew Rate: ±20V/μs (typ)
  - Gain Bandwidth Product: 55MHz (typ)
  - Open Loop Gain (R_L = 600Ω): 140dB (typ)
  - Input Bias Current: 10nA (typ)
  - Input Offset Voltage: 0.1mV (typ)
  - DC Gain Linearity Error: 0.000009%

2 Applications

- Ultra High Quality Audio Amplification
- High Fidelity Preamplifiers
- High Fidelity Multimedia
- State of the Art Phono Pre Amps
- High Performance Professional Audio
- High Fidelity Equalization and Crossover Networks
- High Performance Line Drivers
- High Performance Line Receivers
- High Fidelity Active Filters

3 Description

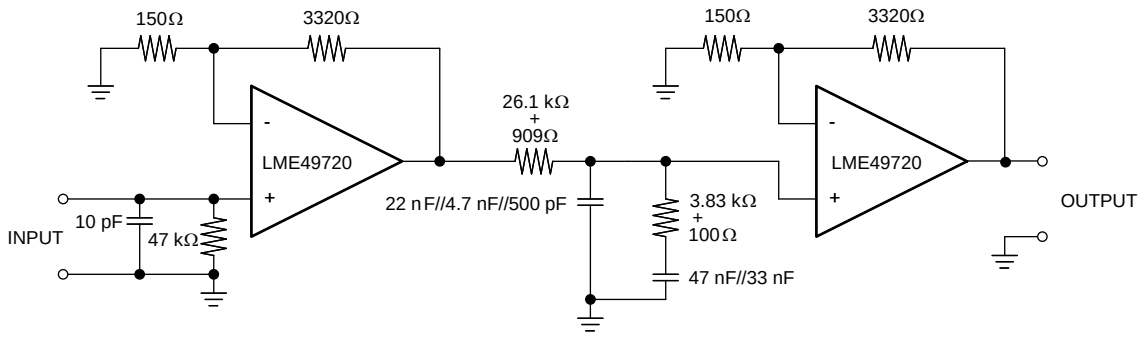
The LME49720 device is part of the ultra-low distortion, low noise, high slew rate operational amplifier series optimized and fully specified for high performance, high fidelity applications. Combining advanced leading-edge process technology with state-of-the-art circuit design, the LME49720 audio operational amplifiers deliver superior audio signal amplification for outstanding audio performance. The LME49720 combines extremely low voltage noise density (2.7nV/√Hz) with vanishingly low THD+N (0.00003%) to easily satisfy the most demanding audio applications.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LME49720	TO-99 (8)	9.08mm × 9.08mm
	SOIC (8)	4.90mm × 3.91mm
	PDIP (8)	9.81mm × 6.35mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Passively Equalized RIAA Phono Preamplifier



Note: 1% metal film resistors, 5% polypropylene capacitors

Table of Contents

4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

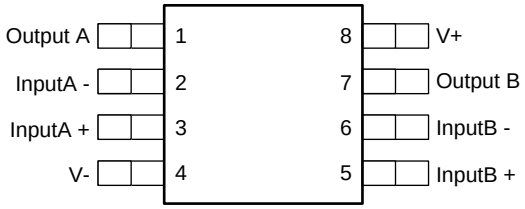
Changes from Revision C (April 2013) to Revision D	Page
• Added *Device Information* table, *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section.	1
• Changed $R_{\theta JA}$ values for D and P packages from 145 °C/W to 107.9 °C/W (D) and from 102 °C/W to 72.9 °C/W (P) in the *Thermal Information* table.	4

5 Device Comparison Table

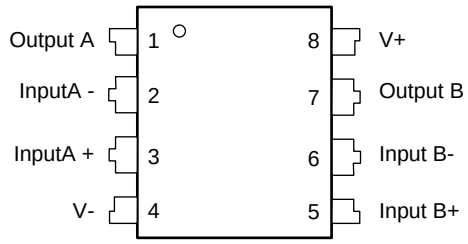
Device Number	Amplifier Type	Number of Channel	Output Current (mA)	Input Noise Density (nV/rtHz)	THD+N (%)
LME49710	Audio Operational	1	37	2.5	0.00003
LME49720	Audio Operational	2	26	2.7	0.00003
LME49721	Audio Operational	2	100	4	0.0002
LME49723	Audio Operational	2	25	3.2	0.0002

6 Pin Configuration and Functions

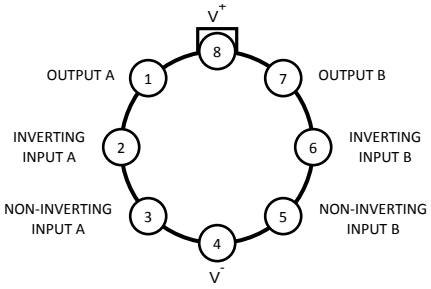
D Package
8 Pin SOIC
Top View



P Packages
8 Pin PDIP
Top View



LMC Package
8 Lead TO-99



Pin Functions

PIN				I/O	DESCRIPTION
NAME	SOIC	PDIP	TO-99		
V+	8	8	8	-	Positive supply voltage
V-	4	4	4	-	Negative supply voltage
InputA-	2	2	2	I	Negative audio input
InputA+	3	3	3	I	Positive audio input
Output A	1	1	1	O	Audio output A
InputB–	6	6	6	I	Negative audio input
InputB+	5	5	5	I	Positive audio input
Output B	7	7	7	O	Audio output B

7 Specifications

7.1 Absolute Maximum Ratings

see (1)(2)(3)

		MIN	MAX	UNIT
Power Supply Voltage	($V_S = V^+ – V^–$)		36	V
Input Voltage		(V–) – 0.7V	(V+) + 0.7	V
Output Short Circuit (4)		Continuous		
Power Dissipation		Internally Limited		
Junction Temperature			150	°C
Temperature Range	$T_{MIN} \le T_A \le T_{MAX}$	–40	85	°C
Supply Voltage Range		±2.5V ≤ V_S ≤ ± 17V		V
Storage Temperature		−65	150	°C

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur.
(2) Operating Ratings indicate conditions for which the device is functional, but do not ensure specific performance limits. For enusred specifications and test conditions, see Electrical Characteristics. The ensured specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.
(3) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
(4) Amplifier output connected to GND, any number of amplifiers within a package.

7.2 ESD Ratings

				VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM) (1)	All pins	2000	V
		Machine Model (MM), per EIAJ IC-121-1981*Application and Implementation*	Pins 1, 4, 7 and 8	200	
			Pins 2, 3, 5 and 6	100	

(1) Human body model, 100pF discharged through a 1.5kΩ resistor.

7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
V+,V–	Supply voltage	±2.5		±17	V
T_A	Operating free-air temperature	–40		85	°C
T_J	Operating junction temperature	–40		150	°C

7.4 Thermal Information

THERMAL METRIC(1)		LME49720			UNIT
		D (SOIC)	P (PDIP)	LMC (TO-99)(2)	
		8 PINS	8 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	107.9	72.9	150	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	52	77.2	35	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	48.3	44.9	–	°C/W
ψ_{JT}	Junction-to-top characterization parameter	8.2	35.7	–	°C/W
ψ_{JB}	Junction-to-board characterization parameter	47.8	49.9	–	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	N/A	–	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.
(2) Thermal performance of a TO-99 package will depend strongly on mounting condition and there is no standard mounting configuration on a JEDEC PCB for that package type.

7.5 Electrical Characteristics

The following specifications apply for V_S = ±15V, R_L = 2kΩ, f_{IN} = 1kHz, and T_A = 25°C, unless otherwise specified.

PARAMETER		TEST CONDITIONS	MIN(1)	TYP (2)	MAX(1)	UNIT
THD+N	Total harmonic distortion + noise	A_V = 1, V_{OUT} = 3V_{rms} R_L = 2kΩ R_L = 600Ω		0.00003 0.00003	0.00009	%
IMD	Intermodulation distortion	A_V = 1, V_{OUT} = 3V_{RMS} Two-tone, 60Hz & 7kHz 4:1		0.00005		%
GBWP	Gain bandwidth product		45	55		MHz
SR	Slew rate		±15	±20		V/µs
FPBW	Full power bandwidth	V_{OUT} = 1V_{P-P}, –3dB referenced to output magnitude at f = 1kHz		10		MHz
t_s	Settling time	A_V = –1, 10V step, C_L = 100pF 0.1% error range		1.2		µs
e_n	Equivalent input noise voltage	f_{BW} = 20Hz to 20kHz		0.34	0.65	µV_{RMS}
	Equivalent input noise density	f = 1kHz f = 10Hz		2.7 6.4	4.7	nV/√Hz
i_n	Current noise density	f = 1kHz f = 10Hz		1.6 3.1		pA/√Hz
V_{OS}	Offset voltage			±0.1	±0.7	mV
$\Delta V_{OS}/\Delta Temp$	Average input offset voltage drift vs temperature	–40°C ≤ T_A ≤ 85°C		0.2		µV/°C
PSRR	Average input offset voltage shift vs power supply voltage	ΔV_S = 20V (3)	110	120		dB
ISO_{CH-CH}	Channel-to-Channel isolation	f_{IN} = 1kHz f_{IN} = 20kHz		118 112		dB
I_B	Input bias current	V_{CM} = 0V		10	72	nA
$\Delta I_{OS}/\Delta Temp$	Input bias current drift vs temperature	–40°C ≤ T_A ≤ 85°C		0.1		nA/°C
I_{OS}	Input offset current	V_{CM} = 0V		11	65	nA
V_{IN-CM}	Common-Mode input voltage range		(V+) – 2.0 (V-) + 2.0	+14.1 –13.9		V
CMRR	Common-Mode rejection	–10V<Vcm<10V	110	120		dB
Z_{IN}	Differential input impedance			30		kΩ
	Common mode input impedance	–10V<Vcm<10V		1000		MΩ
A_{VOL}	Open loop voltage gain	–10V<Vout<10V, R_L = 600Ω	125	140		dB
		–10V<Vout<10V, R_L = 2kΩ		140		
		–10V<Vout<10V, R_L = 10kΩ		140		
V_{OUTMAX}	Maximum output voltage swing	R_L = 600Ω	±12.5	±13.6		V
		R_L = 2kΩ		±14.0		
		R_L = 10kΩ		±14.1		
I_{OUT}	Output current	R_L = 600Ω, V_S = ±17V	±23	±26		mA
I_{OUT-CC}	Instantaneous short circuit current			+53 –42		mA
R_{OUT}	Output impedance	f_{IN} = 10kHz Closed-Loop Open-Loop		0.01 13		Ω
C_{LOAD}	Capacitive load drive overshoot	100pF		16		%
I_S	Total quiescent current	I_{OUT} = 0mA		10	12	mA

(1) Tested limits are ensured to AOQL (Average Outgoing Quality Level).
(2) Typical specifications are specified at +25ºC and represent the most likely parametric norm.
(3) PSRR is measured as follows: V_{OS} is measured at two supply voltages, ±5V and ±15V. PSRR = | 20log($\Delta V_{OS}/\Delta V_S$) |.

7.6 Typical Characteristics

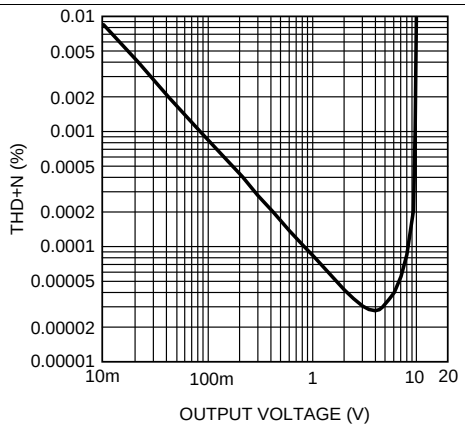


Figure 1. Thd+N vs Output Voltage V_{CC} = 15V, V_{EE} = –15V R_L = 2kΩ

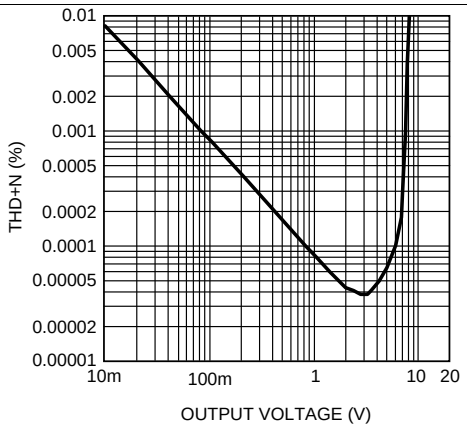


Figure 2. Thd+N vs Output Voltage V_{CC} = 12V, V_{EE} = –12v R_L = 2kΩ

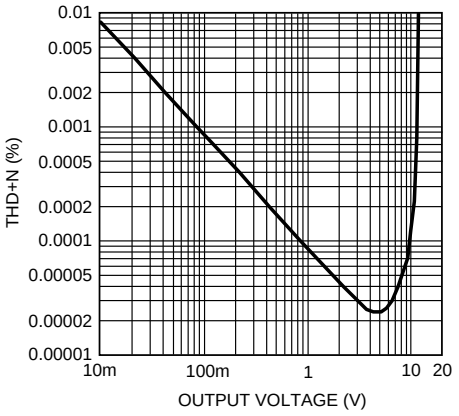


Figure 3. Thd+N vs Output Voltage V_{CC} = 17V, V_{EE} = –17v R_L = 2kΩ

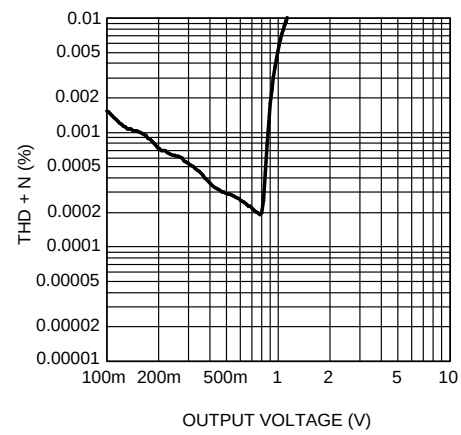


Figure 4. Thd+N vs Output Voltage V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 2kΩ

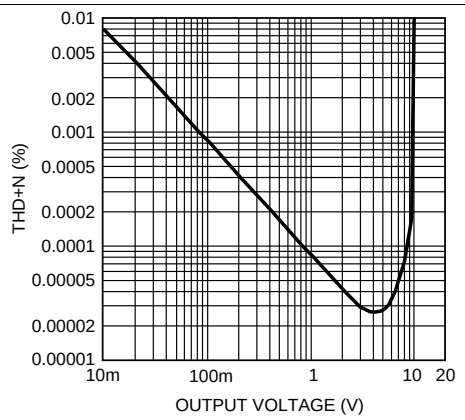


Figure 5. Thd+N vs Output Voltage V_{CC} = 15V, V_{EE} = –15V R_L = 600Ω

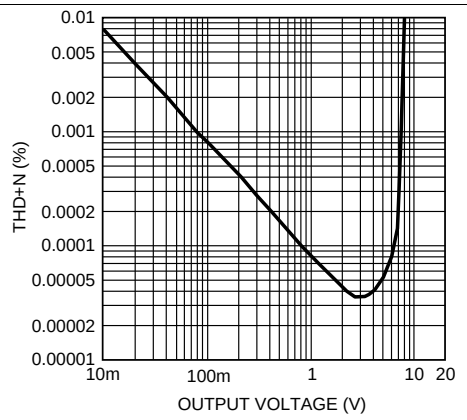


Figure 6. Thd+N vs Output Voltage V_{CC} = 12V, V_{EE} = –12V R_L = 600Ω

Typical Characteristics (continued)

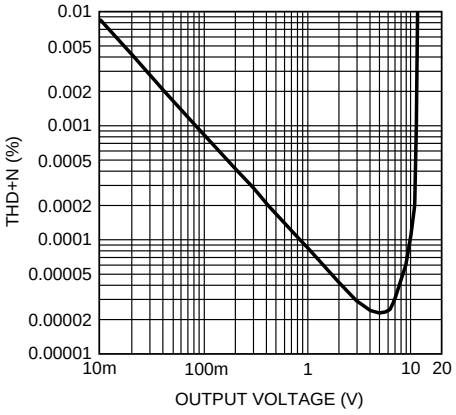


Figure 7. Thd+N vs Output Voltage V_{CC} = 17V, V_{EE} = –17V R_L = 600Ω

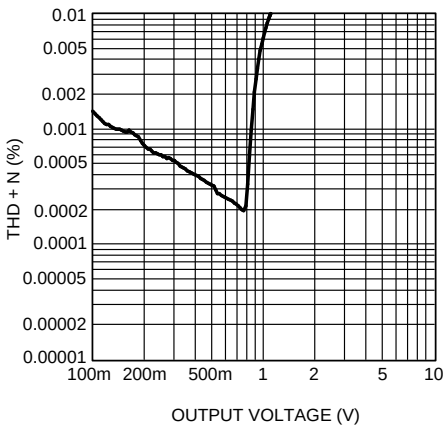


Figure 8. Thd+N vs Output Voltage V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 600Ω

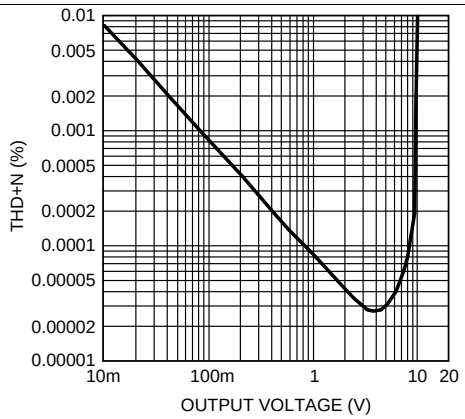


Figure 9. Thd+N vs Output Voltage V_{CC} = 15V, V_{EE} = –15V R_L = 10kΩ

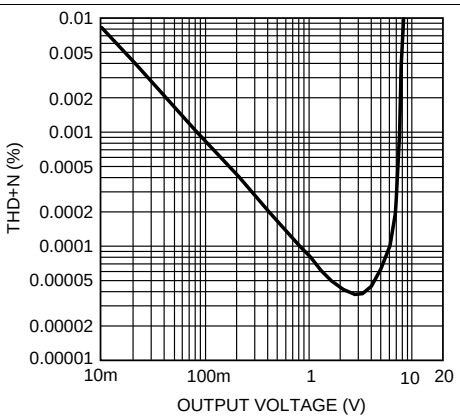


Figure 10. Thd+N vs Output Voltage V_{CC} = 12V, V_{EE} = –12V R_L = 10kΩ

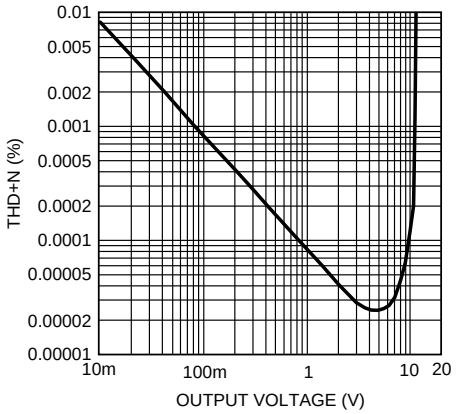


Figure 11. Thd+N vs Output Voltage V_{CC} = 17V, V_{EE} = –17V R_L = 10kΩ

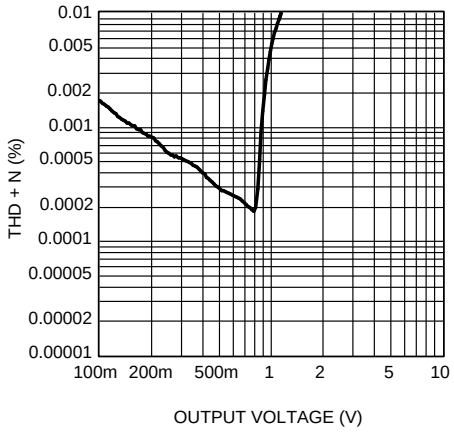


Figure 12. Thd+N vs Output Voltage V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 10kΩ

Typical Characteristics (continued)

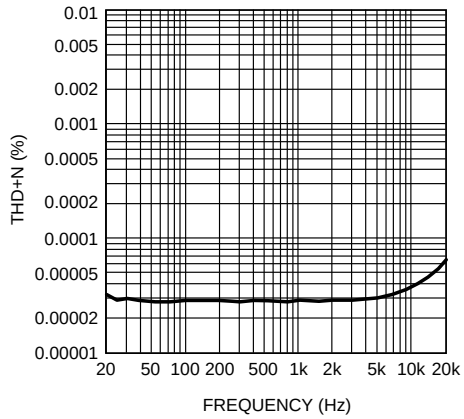


Figure 13. Thd+N vs Frequency V_{CC} = 15V, V_{EE} = –15V, V_{OUT} = 3V_{RMS} R_L = 2kΩ

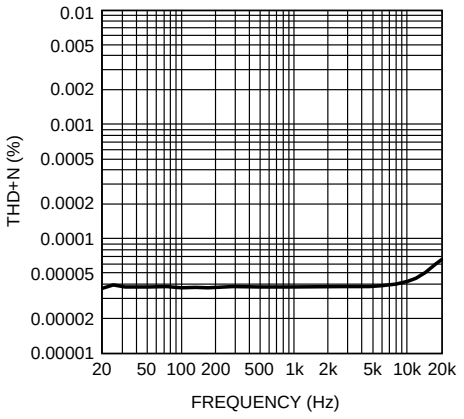


Figure 14. Thd+N vs Frequency V_{CC} = 12V, V_{EE} = –12V, V_{OUT} = 3V_{RMS} R_L = 2kΩ

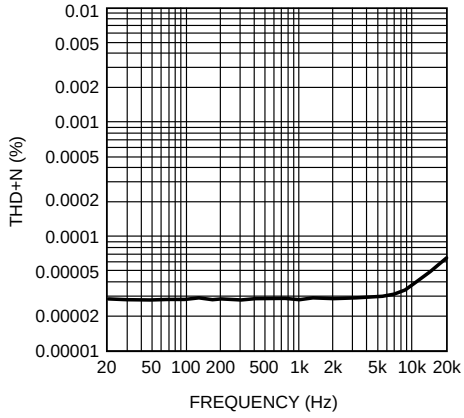


Figure 15. Thd+N vs Frequency V_{CC} = 17V, V_{EE} = –17V, V_{OUT} = 3V_{RMS} R_L = 2kΩ

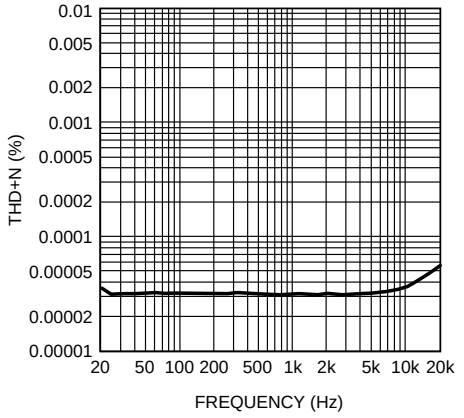


Figure 16. Thd+N vs Frequency V_{CC} = 15V, V_{EE} = –15V, V_{OUT} = 3V_{RMS} R_L = 600Ω

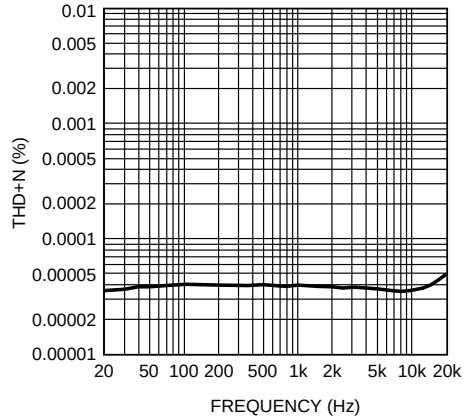


Figure 17. Thd+N vs Frequency V_{CC} = 12V, V_{EE} = –12V, V_{OUT} = 3V_{RMS} R_L = 600Ω

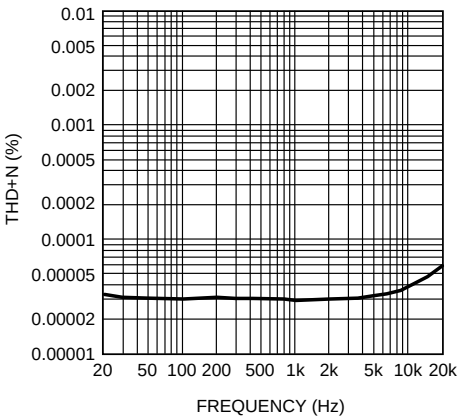


Figure 18. Thd+N vs Frequency V_{CC} = 17V, V_{EE} = –17V, V_{OUT} = 3V_{RMS} R_L = 600Ω

Typical Characteristics (continued)

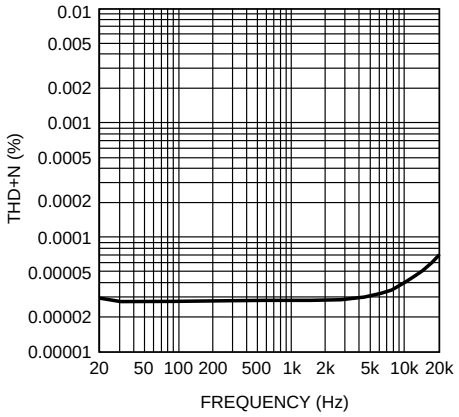


Figure 19. Thd+N vs Frequency V_{CC} = 15V, V_{EE} = –15V, V_{OUT} = 3V_{RMS} R_L = 10kΩ

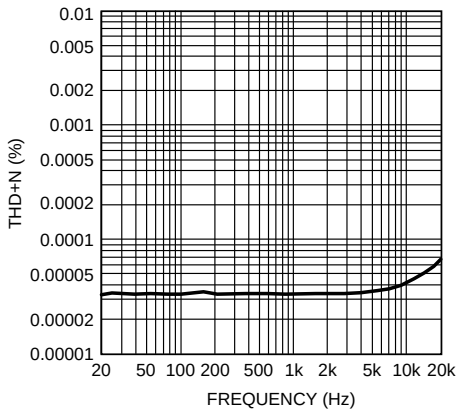


Figure 20. Thd+N vs Frequency V_{CC} = 12V, V_{EE} = –12V, V_{OUT} = 3V_{RMS} R_L = 10kΩ

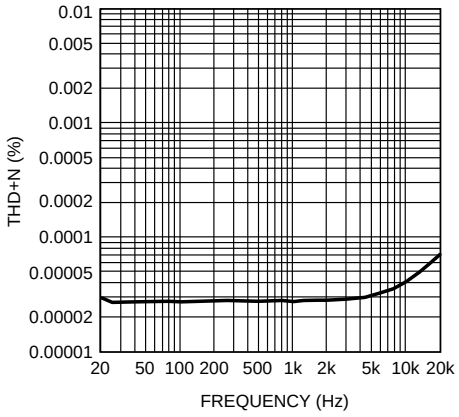


Figure 21. Thd+N vs Frequency V_{CC} = 17V, V_{EE} = –17V, V_{OUT} = 3V_{RMS} R_L = 10kΩ

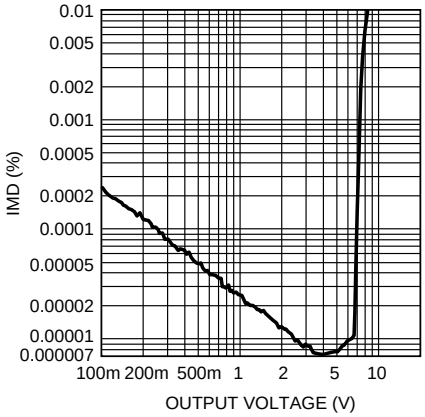


Figure 22. IMD vs Output Voltage V_{CC} = 15V, V_{EE} = –15V R_L = 2kΩ

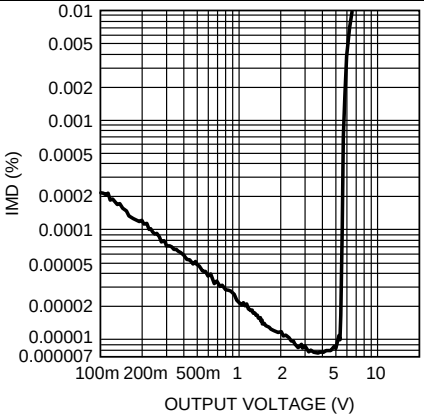


Figure 23. IMD vs Output Voltage V_{CC} = 12V, V_{EE} = –12V R_L = 2kΩ

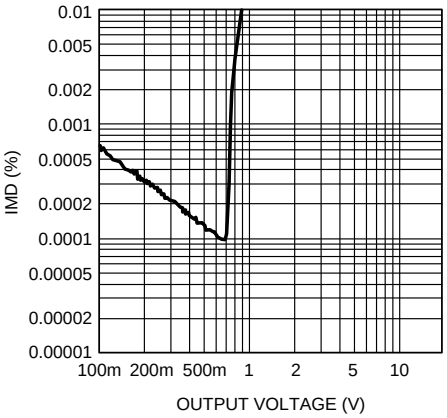


Figure 24. IMD vs Output Voltage V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 2kΩ

Typical Characteristics (continued)

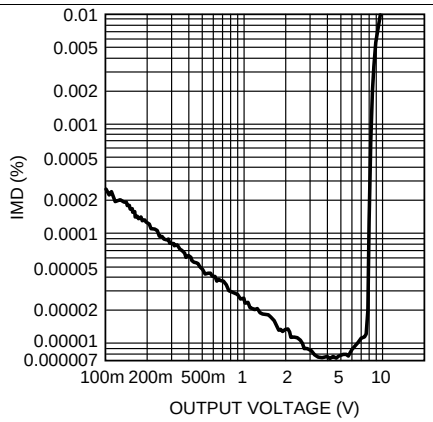


Figure 25. IMD vs Output Voltage V_{CC} = 17V, V_{EE} = –17V R_L = 2kΩ

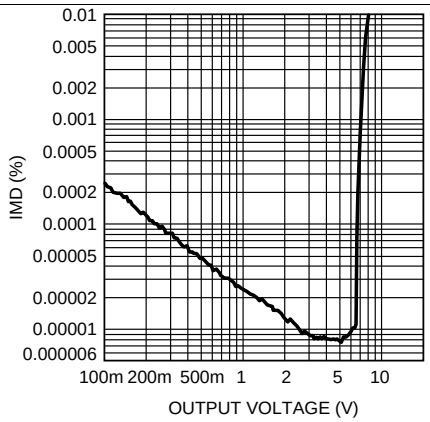


Figure 26. IMD vs Output Voltage V_{CC} = 15V, V_{EE} = –15V R_L = 600Ω

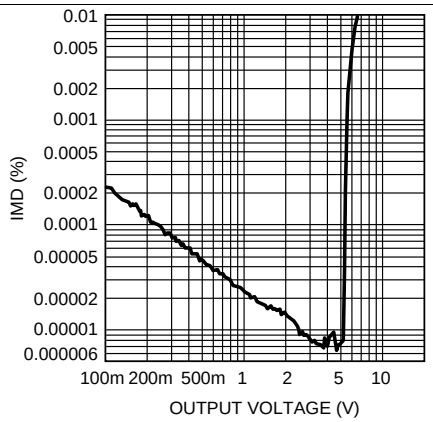


Figure 27. IMD vs Output Voltage V_{CC} = 12V, V_{EE} = –12V R_L = 600Ω

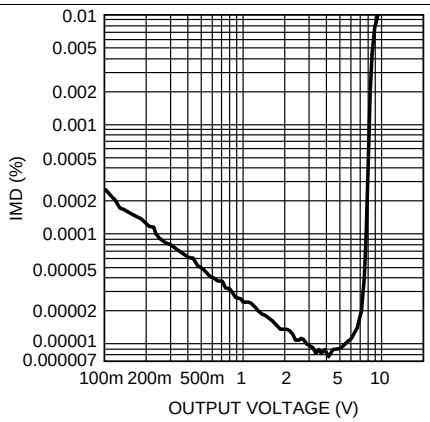


Figure 28. IMD vs Output Voltage V_{CC} = 17V, V_{EE} = –17V R_L = 600Ω

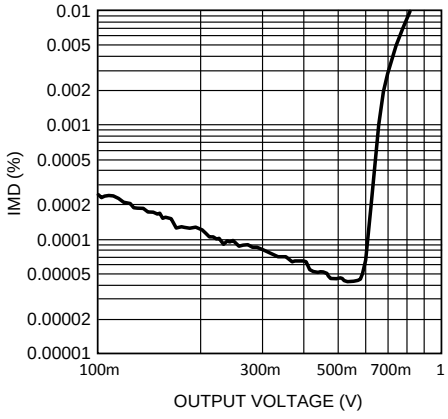


Figure 29. IMD vs Output Voltage V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 600Ω

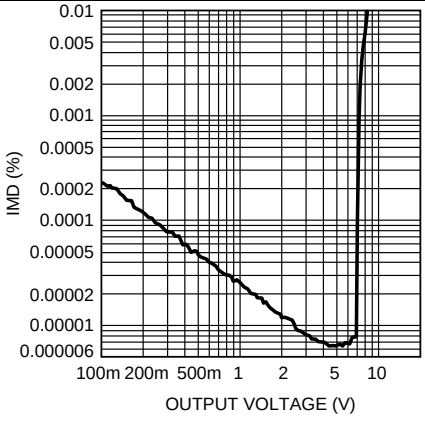


Figure 30. IMD vs Output Voltage V_{CC} = 15V, V_{EE} = –15V R_L = 10kΩ

Typical Characteristics (continued)

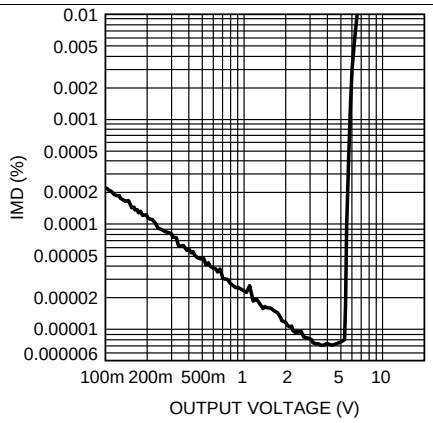


Figure 31. IMD vs Output Voltage V_{CC} = 12V, V_{EE} = –12V R_L = 10kΩ

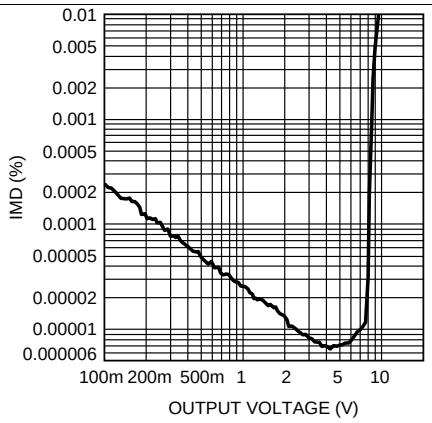


Figure 32. IMD vs Output Voltage V_{CC} = 17V, V_{EE} = –17V R_L = 10kΩ

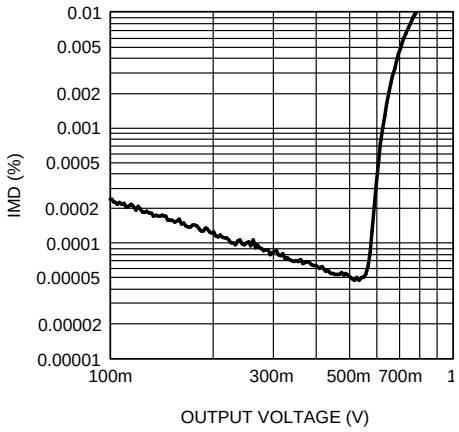


Figure 33. IMD vs Output Voltage V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 10kΩ

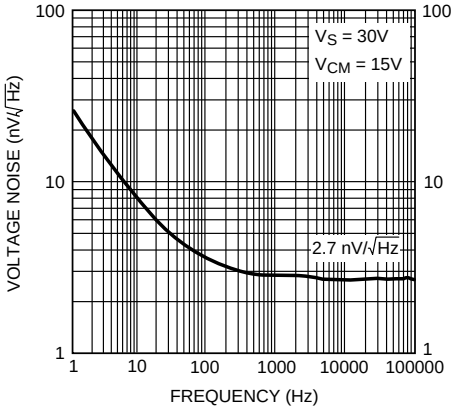


Figure 34. Voltage Noise Density vs Frequency

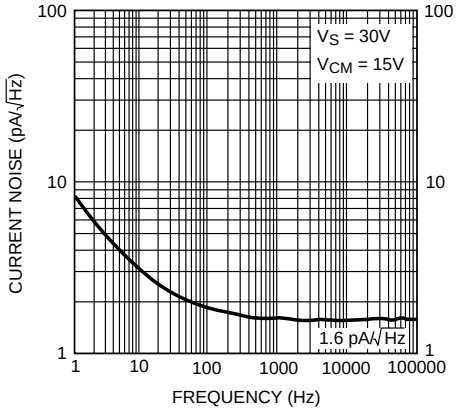


Figure 35. Current Noise Density vs Frequency

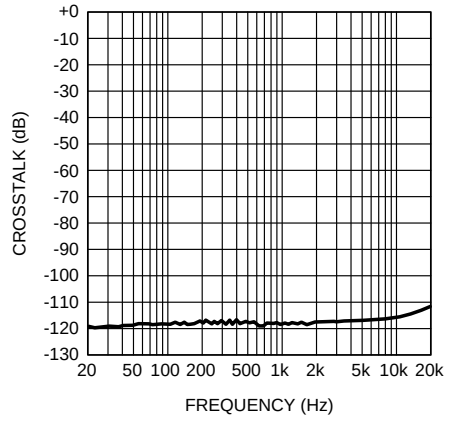


Figure 36. Crosstalk vs Frequency V_{CC} = 15V, V_{EE} = –15V, V_{OUT} = 3V_{RMS} A_V = 0dB, R_L = 2kΩ

Typical Characteristics (continued)

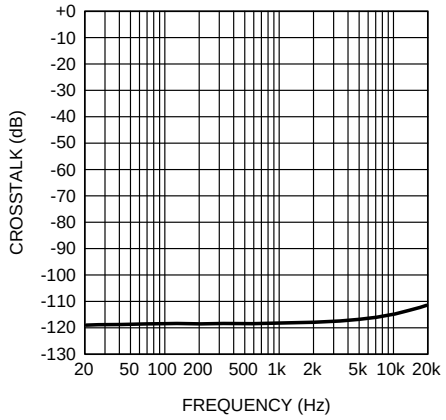


Figure 37. Crosstalk vs Frequency V_{CC} = 15V, V_{EE} = –15V, V_{OUT} = 10V_{RMS} A_V = 0dB, R_L = 2kΩ

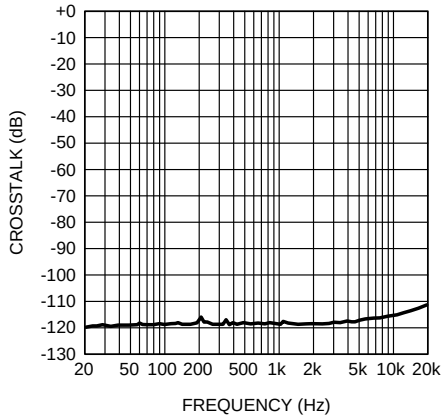


Figure 38. Crosstalk vs Frequency V_{CC} = 12V, V_{EE} = –12V, V_{OUT} = 3V_{RMS} A_V = 0dB, R_L = 2kΩ

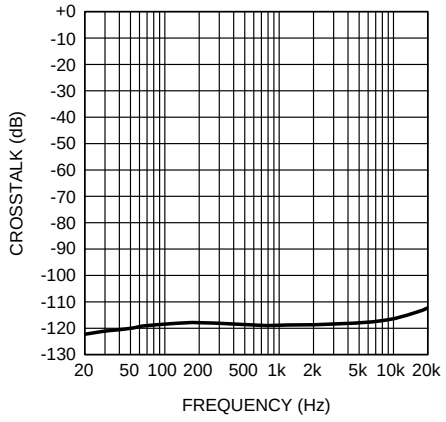


Figure 39. Crosstalk vs Frequency V_{CC} = 12V, V_{EE} = –12V, V_{OUT} = 10V_{RMS} A_V = 0dB, R_L = 2kΩ

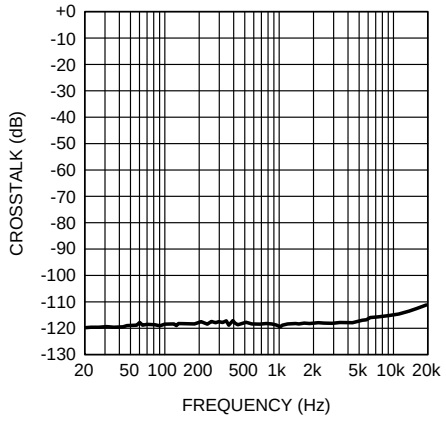


Figure 40. Crosstalk vs Frequency V_{CC} = 17V, V_{EE} = –17V, V_{OUT} = 3V_{RMS} A_V = 0dB, R_L = 2kΩ

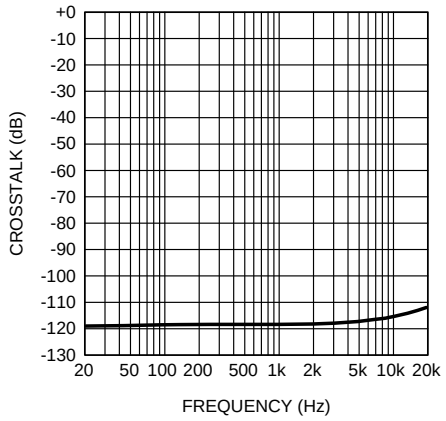


Figure 41. Crosstalk vs Frequency V_{CC} = 17V, V_{EE} = –17V, V_{OUT} = 10V_{RMS} A_V = 0dB, R_L = 2kΩ

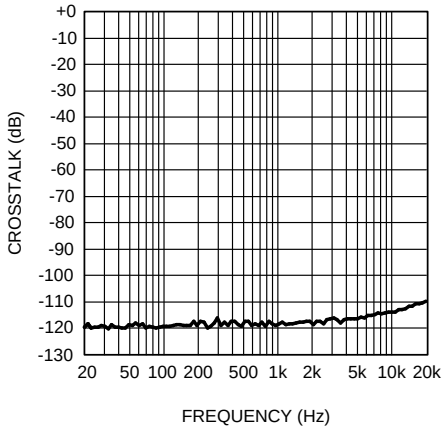


Figure 42. Crosstalk vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V, V_{OUT} = 1V_{RMS} A_V = 0dB, R_L = 2kΩ

Typical Characteristics (continued)

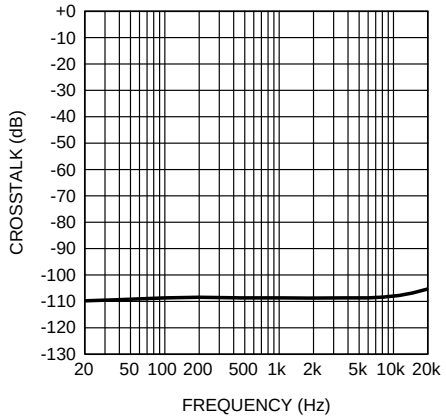


Figure 43. Crosstalk vs Frequency V_{CC} = 15V, V_{EE} = –15V, V_{OUT} = 3V_{RMS} A_V = 0dB, R_L = 600Ω

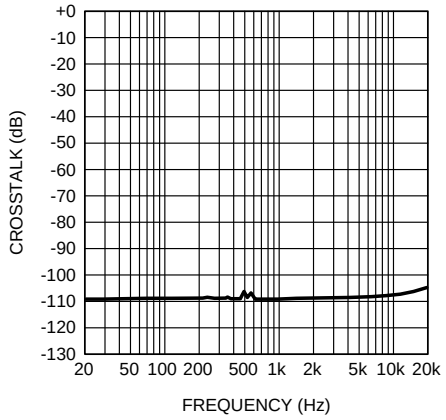


Figure 44. Crosstalk vs Frequency V_{CC} = 15V, V_{EE} = –15V, V_{OUT} = 10V_{RMS} A_V = 0dB, R_L = 600Ω

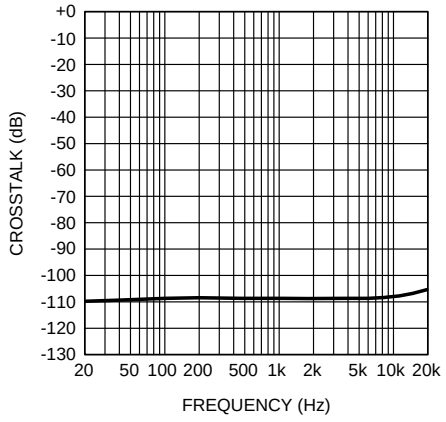


Figure 45. Crosstalk vs Frequency V_{CC} = 12V, V_{EE} = –12V, V_{OUT} = 3V_{RMS} A_V = 0dB, R_L = 600Ω

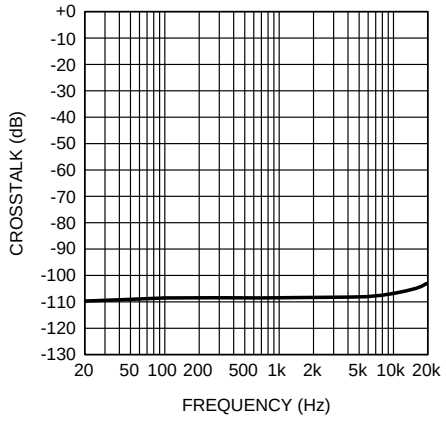


Figure 46. Crosstalk vs Frequency V_{CC} = 12V, V_{EE} = –12V, V_{OUT} = 10V_{RMS} A_V = 0dB, R_L = 600Ω

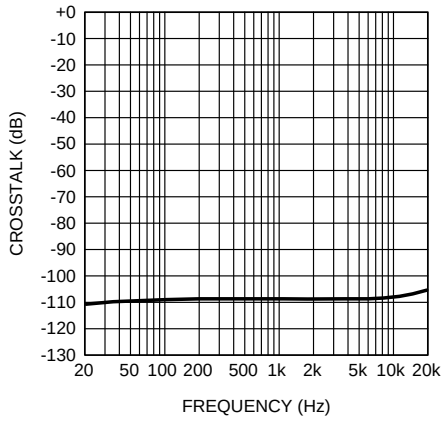


Figure 47. Crosstalk vs Frequency V_{CC} = 17V, V_{EE} = –17V, V_{OUT} = 3V_{RMS} A_V = 0dB, R_L = 600Ω

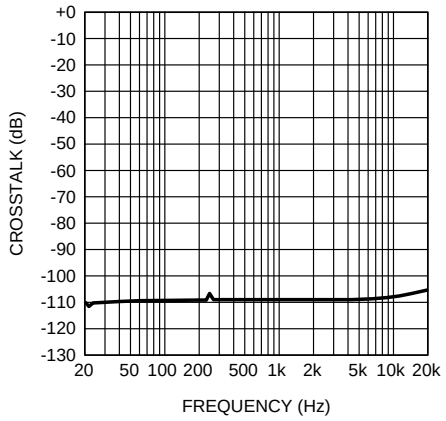


Figure 48. Crosstalk vs Frequency V_{CC} = 17V, V_{EE} = –17V, V_{OUT} = 10V_{RMS} A_V = 0dB, R_L = 600Ω

Typical Characteristics (continued)

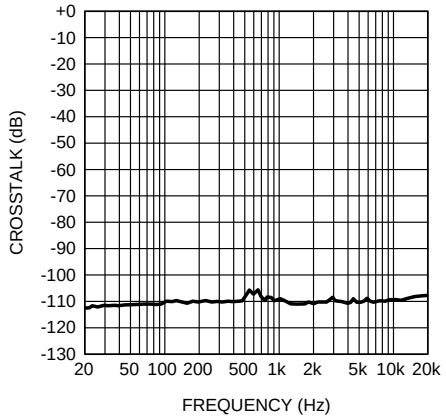


Figure 49. Crosstalk vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V, V_{OUT} = 1V_{RMS} A_V = 0dB, R_L = 600Ω

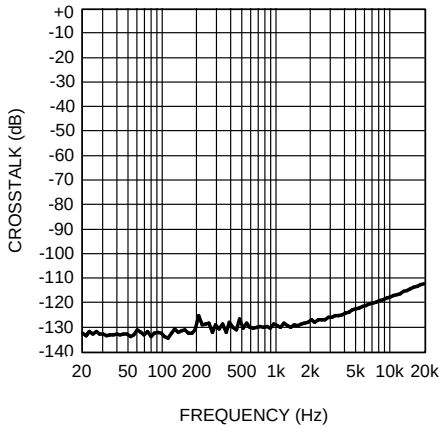


Figure 50. Crosstalk vs Frequency V_{CC} = 15V, V_{EE} = –15V, V_{OUT} = 3V_{RMS} A_V = 0dB, R_L = 10kΩ

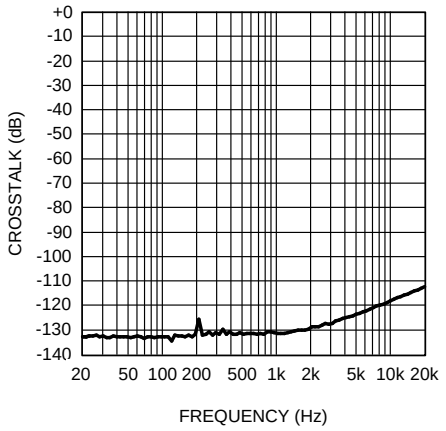


Figure 51. Crosstalk vs Frequency V_{CC} = 15V, V_{EE} = –15V, V_{OUT} = 10V_{RMS} A_V = 0dB, R_L = 10kΩ

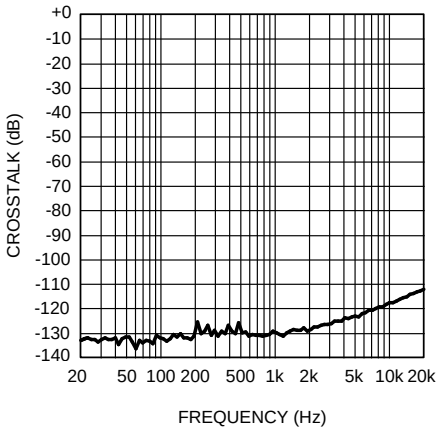


Figure 52. Crosstalk vs Frequency V_{CC} = 12V, V_{EE} = –12V, V_{OUT} = 3V_{RMS} A_V = 0dB, R_L = 10kΩ

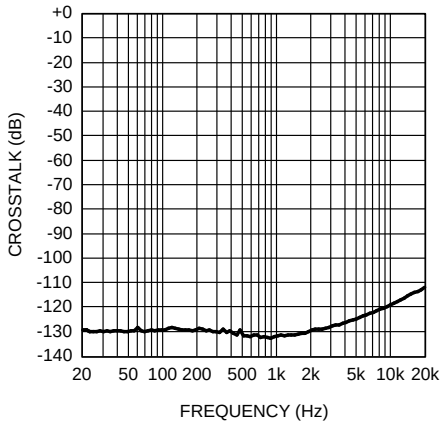


Figure 53. Crosstalk vs Frequency V_{CC} = 12V, V_{EE} = –12V, V_{OUT} = 10V_{RMS} A_V = 0dB, R_L = 10kΩ

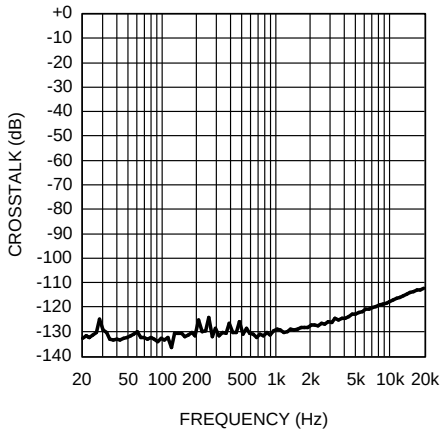


Figure 54. Crosstalk vs Frequency V_{CC} = 17V, V_{EE} = –17V, V_{OUT} = 3V_{RMS} A_V = 0dB, R_L = 10kΩ

Typical Characteristics (continued)

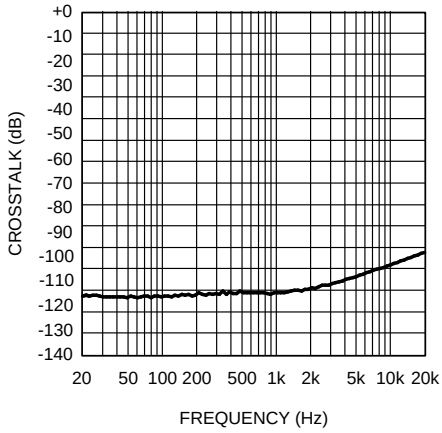


Figure 55. Crosstalk vs Frequency V_{CC} = 17V, V_{EE} = –17V, V_{OUT} = 10V_{RMS} A_V = 0dB, R_L = 10kΩ

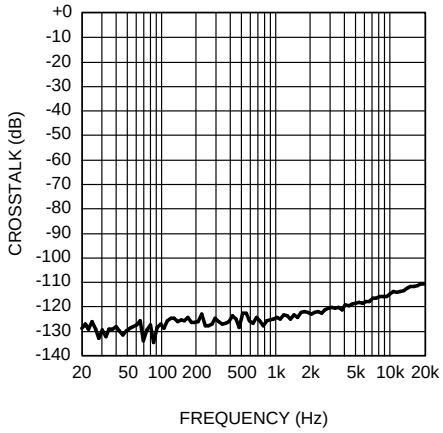


Figure 56. Crosstalk vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V, V_{OUT} = 1V_{RMS} A_V = 0dB, R_L = 10kΩ

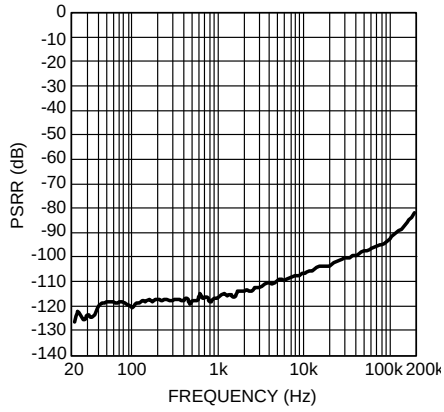


Figure 57. PSRR+ vs Frequency V_{CC} = 15V, V_{EE} = –15V R_L = 10kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

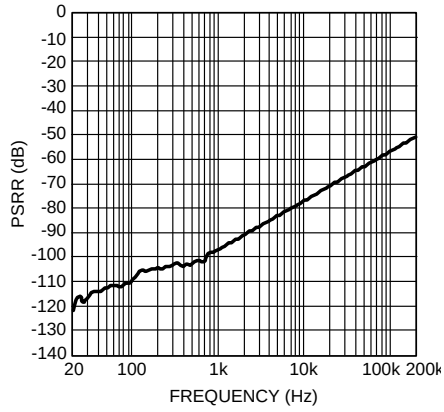


Figure 58. PSRR- vs Frequency V_{CC} = 15V, V_{EE} = –15V R_L = 10kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

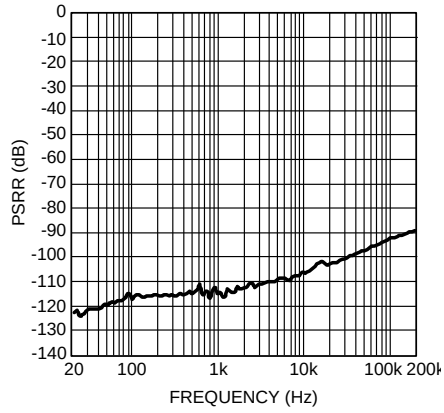


Figure 59. PSRR+ vs Frequency V_{CC} = 15V, V_{EE} = –15V R_L = 2kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

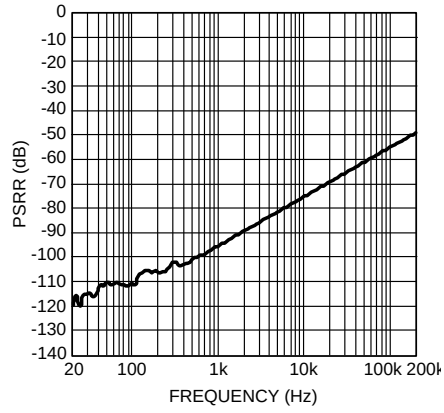


Figure 60. PSRR- vs Frequency V_{CC} = 15V, V_{EE} = –15V R_L = 2kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

Typical Characteristics (continued)

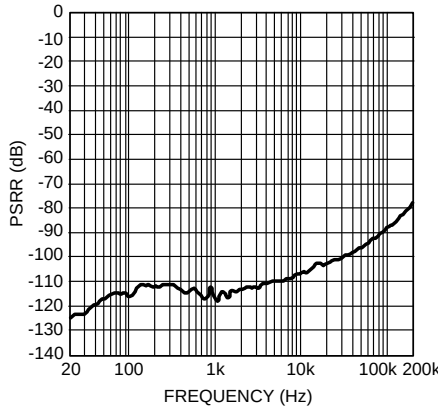


Figure 61. PSRR+ vs Frequency V_{CC} = 15V, V_{EE} = –15V R_L = 600Ω, F = 200kHz, V_{RIPPLE} = 200mvpp

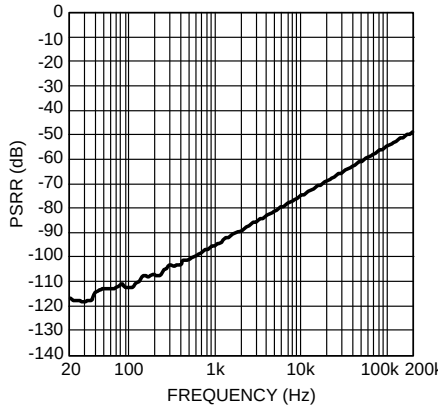


Figure 62. PSRR- vs Frequency V_{CC} = 15V, V_{EE} = –15V R_L = 600Ω, F = 200kHz, V_{RIPPLE} = 200mvpp

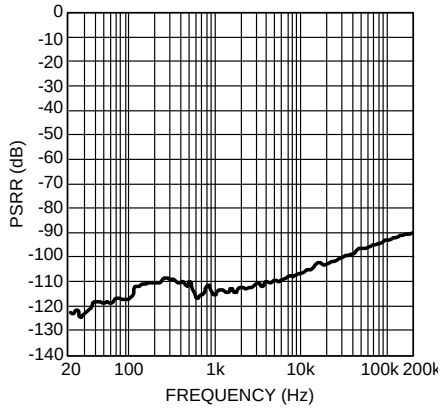


Figure 63. PSRR+ vs Frequency V_{CC} = 12V, V_{EE} = –12V R_L = 10kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

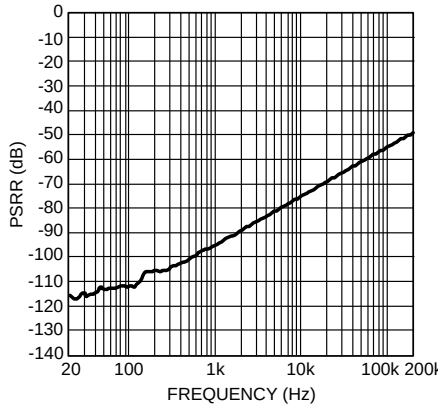


Figure 64. PSRR– vs Frequency V_{CC} = 12V, V_{EE} = –12V R_L = 10kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

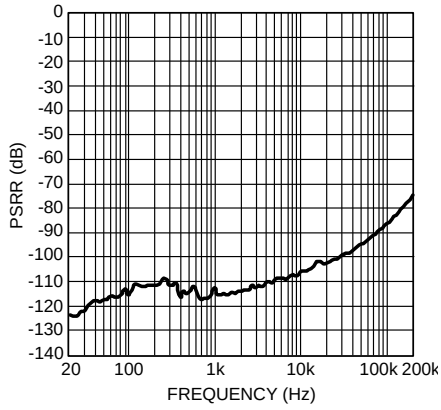


Figure 65. PSRR+ vs Frequency V_{CC} = 12V, V_{EE} = –12V R_L = 2kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

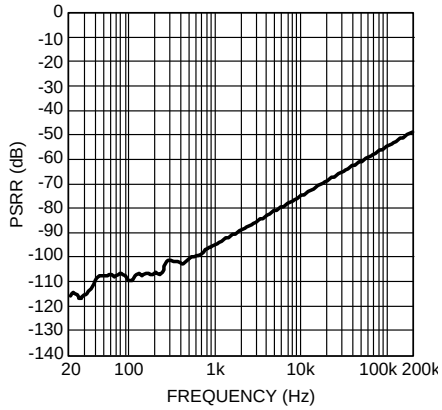


Figure 66. PSRR– vs Frequency V_{CC} = 12V, V_{EE} = –12V R_L = 2kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

Typical Characteristics (continued)

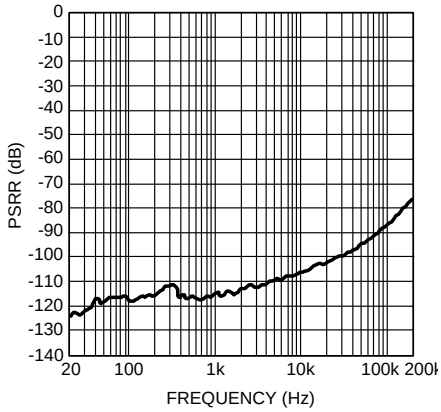


Figure 67. PSRR+ vs Frequency V_{CC} = 12V, V_{EE} = –12V R_L = 600Ω, F = 200kHz, V_{RIPPLE} = 200mvpp

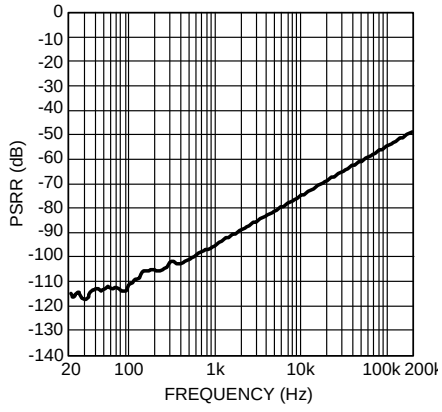


Figure 68. PSRR– vs Frequency V_{CC} = 12V, V_{EE} = –12V R_L = 600Ω, F = 200kHz, V_{RIPPLE} = 200mvpp

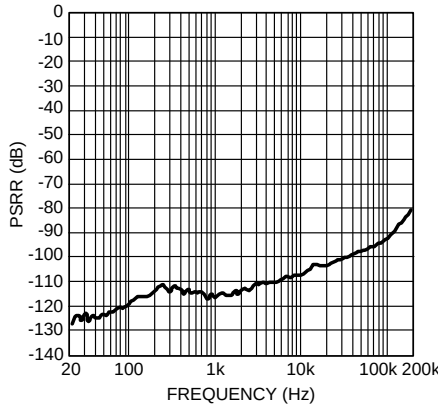


Figure 69. PSRR+ vs Frequency V_{CC} = 17V, V_{EE} = –17V R_L = 10kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

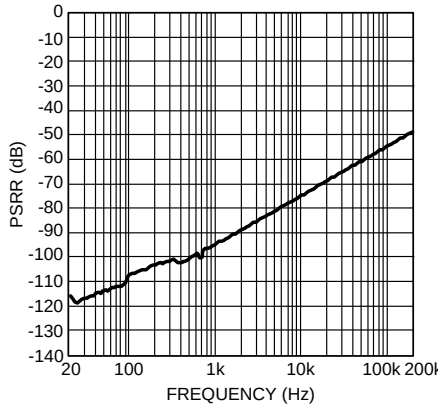


Figure 70. PSRR– vs Frequency V_{CC} = 17V, V_{EE} = –17V R_L = 10kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

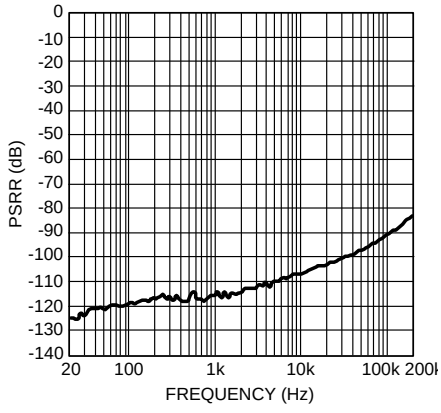


Figure 71. PSRR+ vs Frequency V_{CC} = 17V, V_{EE} = –17V R_L = 2kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

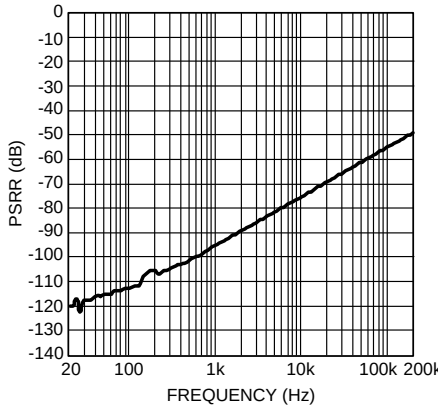


Figure 72. PSRR– vs Frequency V_{CC} = 17V, V_{EE} = –17V R_L = 2kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

Typical Characteristics (continued)

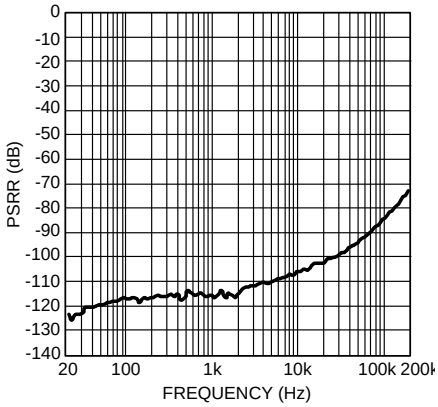


Figure 73. PSRR+ vs Frequency V_{CC} = 17V, V_{EE} = –17V R_L = 600Ω, F = 200kHz, V_{RIPPLE} = 200mvpp

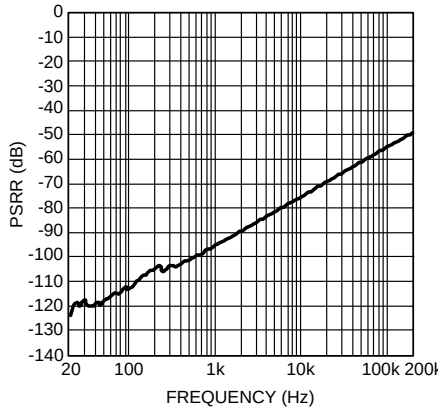


Figure 74. PSRR– vs Frequency V_{CC} = 17V, V_{EE} = –17V R_L = 600Ω, F = 200kHz, V_{RIPPLE} = 200mvpp

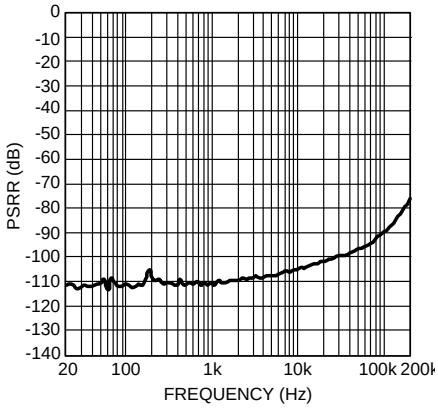


Figure 75. PSRR+ vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 10kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

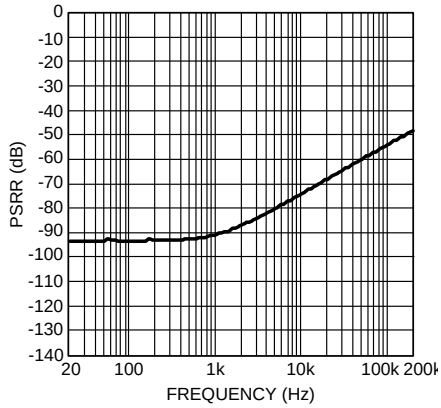


Figure 76. PSRR– vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 10kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

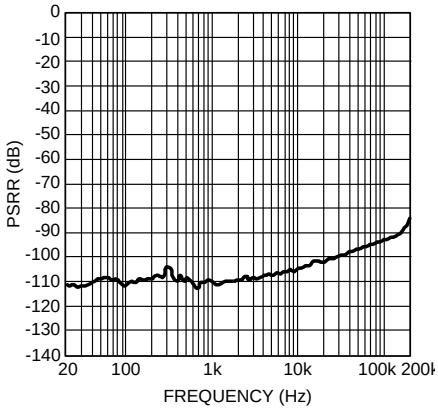


Figure 77. PSRR+ vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 2kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

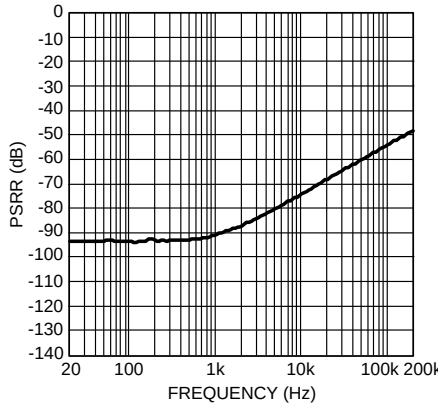


Figure 78. PSRR– vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 2kΩ, F = 200kHz, V_{RIPPLE} = 200mvpp

Typical Characteristics (continued)

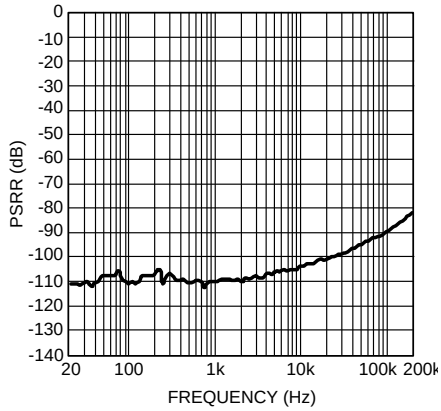


Figure 79. PSRR+ vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 600Ω, F = 200kHz, V_{RIPPLE} = 200mvpp

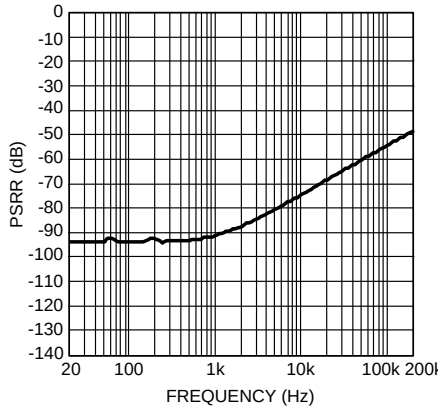


Figure 80. PSRR– vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 600Ω, F = 200kHz, V_{RIPPLE} = 200mvpp

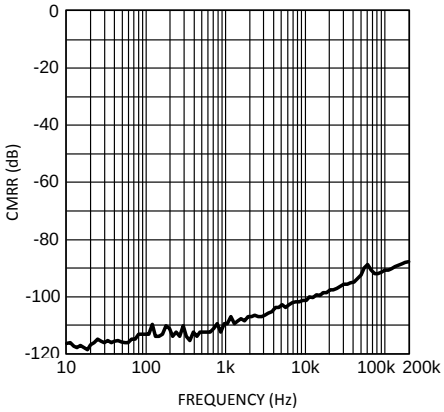


Figure 81. Cmrr vs Frequency V_{CC} = 15V, V_{EE} = –15V R_L = 2kΩ

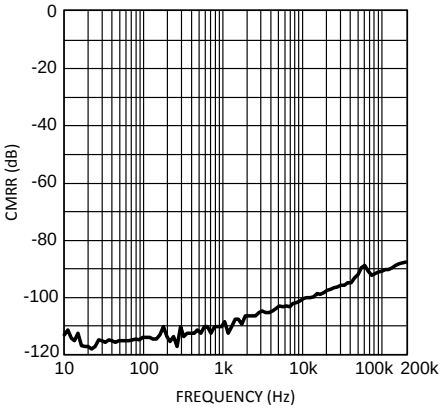


Figure 82. Cmrr vs Frequency V_{CC} = 12V, V_{EE} = –12V R_L = 2kΩ

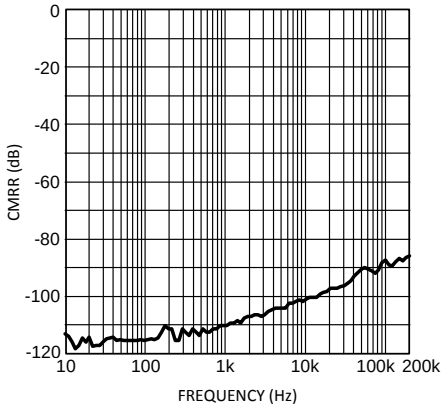


Figure 83. Cmrr vs Frequency V_{CC} = 17V, V_{EE} = –17V R_L = 2kΩ

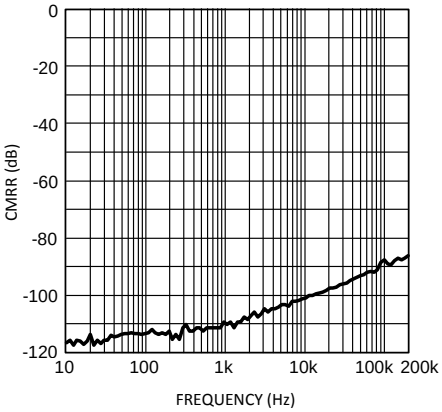


Figure 84. Cmrr vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 2kΩ

Typical Characteristics (continued)

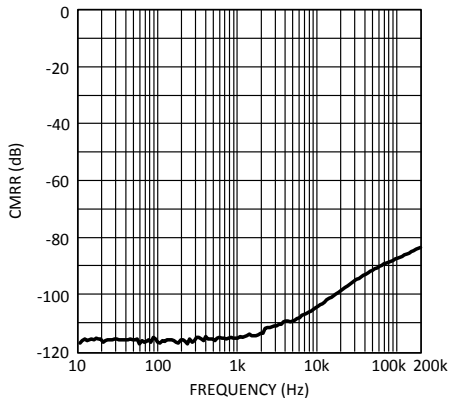


Figure 85. Cmrr vs Frequency V_{CC} = 15V, V_{EE} = –15V R_L = 600Ω

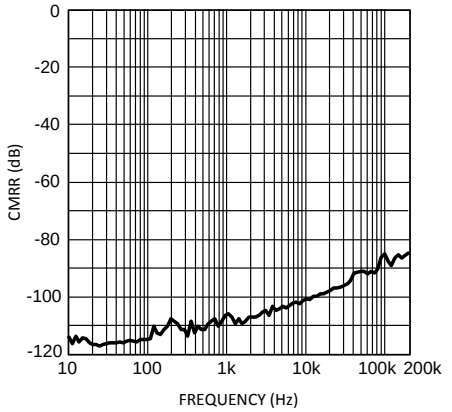


Figure 86. Cmrr vs Frequency V_{CC} = 12V, V_{EE} = –12V R_L = 600Ω

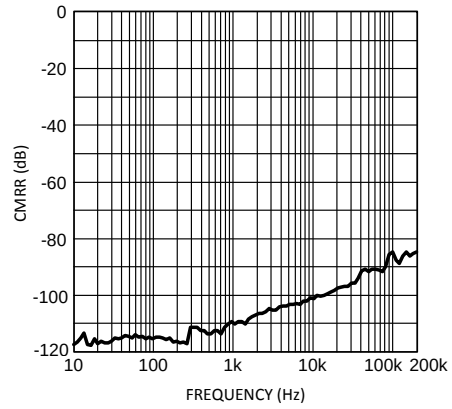


Figure 87. Cmrr vs Frequency V_{CC} = 17V, V_{EE} = –17V R_L = 600Ω

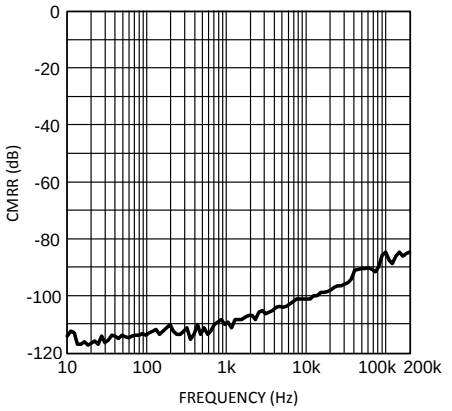


Figure 88. Cmrr vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 600Ω

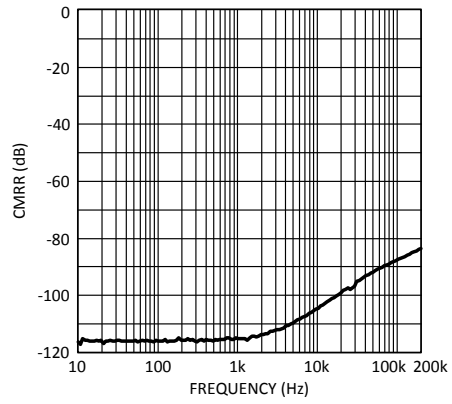


Figure 89. Cmrr vs Frequency V_{CC} = 15V, V_{EE} = –15V R_L = 10kΩ

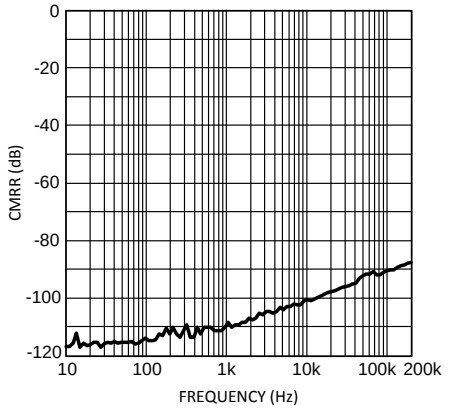


Figure 90. Cmrr vs Frequency V_{CC} = 12V, V_{EE} = –12V R_L = 10kΩ

Typical Characteristics (continued)

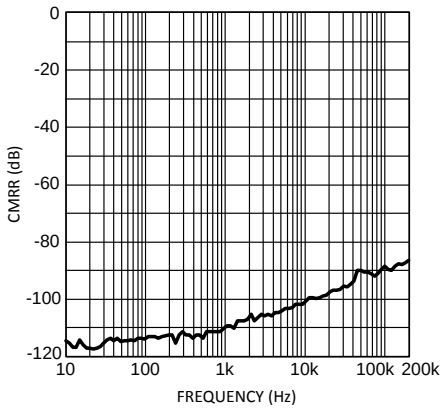


Figure 91. Cmrr vs Frequency V_{CC} = 17V, V_{EE} = –17V R_L = 10kΩ

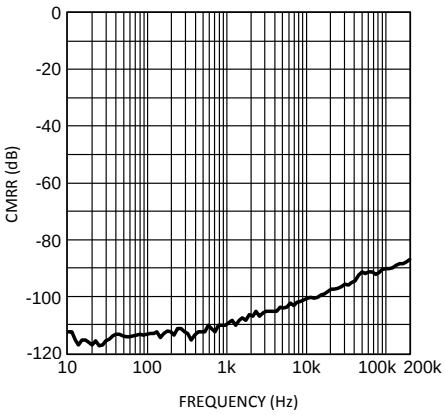


Figure 92. Cmrr vs Frequency V_{CC} = 2.5V, V_{EE} = –2.5V R_L = 10kΩ

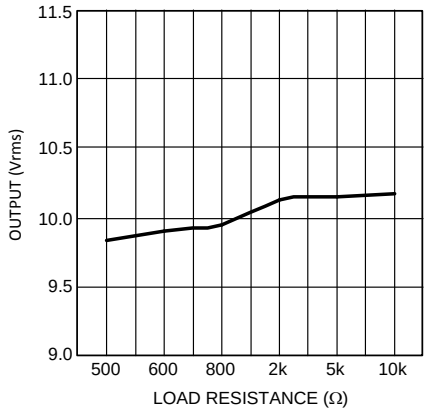


Figure 93. Output Voltage vs Load Resistance V_{DD} = 15V, V_{EE} = –15v Thd+N = 1%

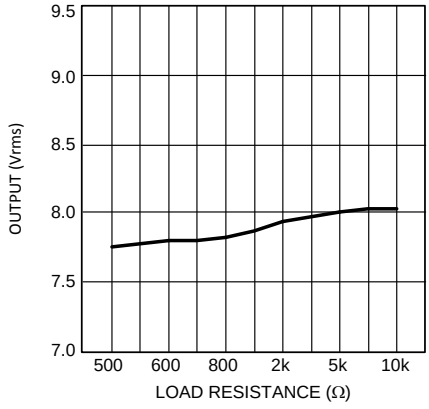


Figure 94. Output Voltage vs Load Resistance V_{DD} = 12V, V_{EE} = –12v Thd+N = 1%

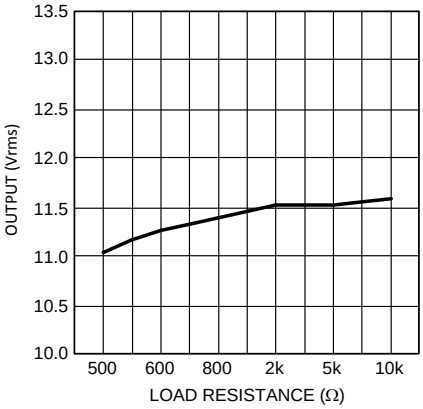


Figure 95. Output Voltage vs Load Resistance V_{DD} = 17V, V_{EE} = –17v Thd+N = 1%

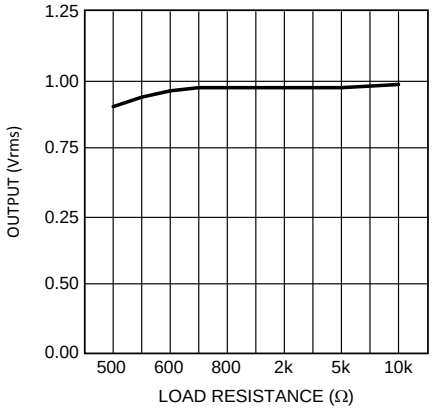


Figure 96. Output Voltage vs Load Resistance V_{DD} = 2.5V, V_{EE} = –2.5v Thd+N = 1%

Typical Characteristics (continued)

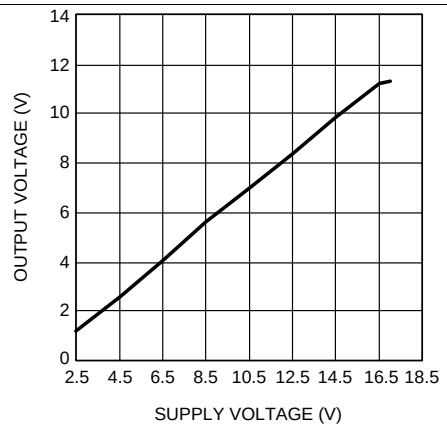


Figure 97. Output Voltage vs Supply Voltage R_L = 2kΩ, Thd+N = 1%

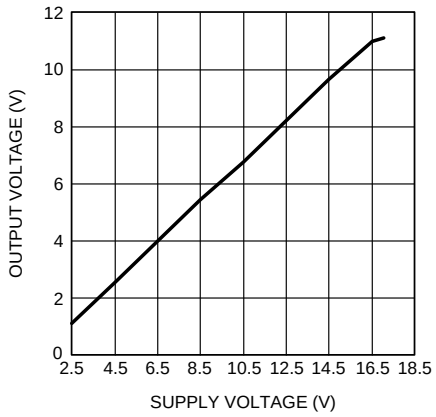


Figure 98. Output Voltage vs Supply Voltage R_L = 600Ω, Thd+N = 1%

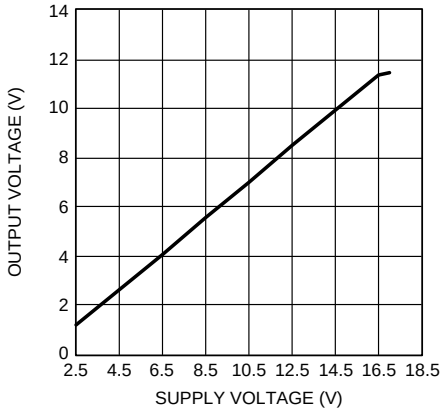


Figure 99. Output Voltage vs Supply Voltage R_L = 10kΩ, Thd+N = 1%

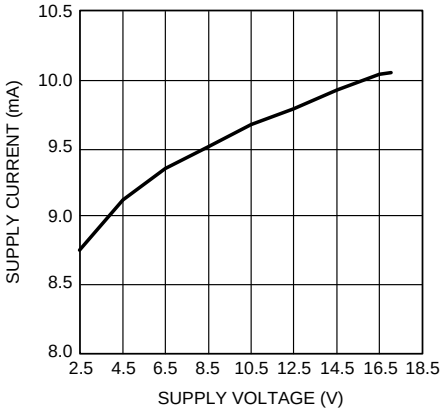


Figure 100. Supply Current vs Supply Voltage R_L = 2kΩ

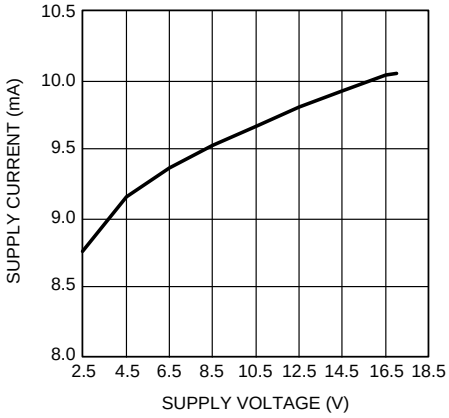


Figure 101. Supply Current vs Supply Voltage R_L = 600Ω

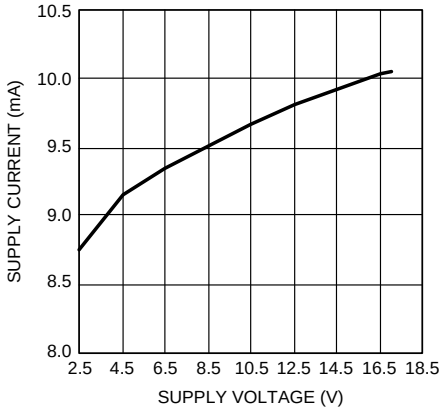


Figure 102. Supply Current vs Supply Voltage R_L = 10kΩ

Typical Characteristics (continued)

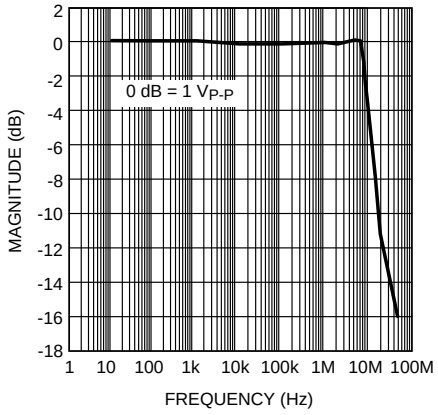


Figure 103. Full Power Bandwidth vs Frequency

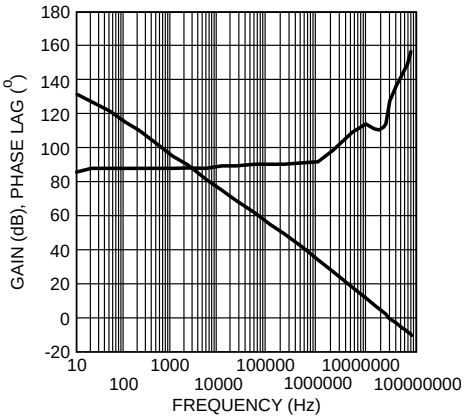


Figure 104. Gain Phase vs Frequency

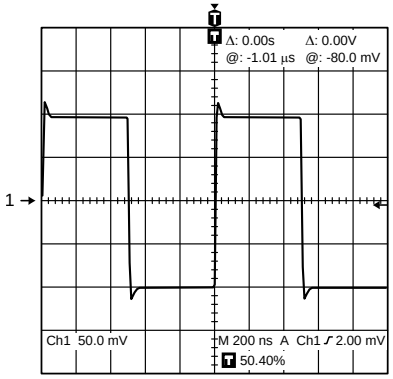


Figure 105. Small-Signal Transient Response A_V = 1, C_L = 10pf

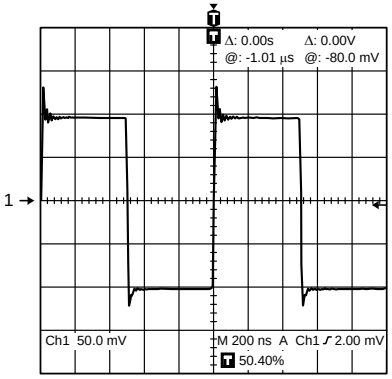


Figure 106. Small-Signal Transient Response A_V = 1, C_L = 100pf

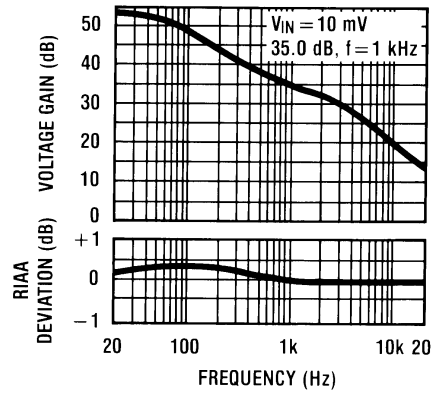


Figure 107. RIAA Preamp Voltage Gain, RIAA Deviation vs Frequency

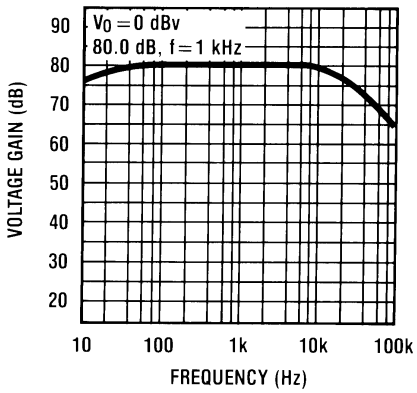


Figure 108. Flat Amp Voltage Gain vs Frequency

8 Parameter Measurement Information

All parameters are measured according to the conditions described in the *Specifications* section.

8.1 Distortion Measurements

The vanishingly low residual distortion produced by LME49720 is below the capabilities of all commercially available equipment. This makes distortion measurements just slightly more difficult than simply connecting a distortion meter to the amplifier's inputs and outputs. The solution, however, is quite simple: an additional resistor. Adding this resistor extends the resolution of the distortion measurement equipment.

The LME49720's low residual distortion is an input referred internal error. As shown in Figure 109, adding the 10Ω resistor connected between the amplifier's inverting and non-inverting inputs changes the amplifier's noise gain. The result is that the error signal (distortion) is amplified by a factor of 101. Although the amplifier's closed-loop gain is unaltered, the feedback available to correct distortion errors is reduced by 101, which means that measurement resolution increases by 101. To ensure minimum effects on distortion measurements, keep the value of R1 low as shown in Figure 109.

This technique is verified by duplicating the measurements with high closed loop gain and/or making the measurements at high frequencies. Doing so produces distortion components that are within the measurement equipment's capabilities. This datasheet's THD+N and IMD values were generated using the above described circuit connected to an Audio Precision System Two Cascade.

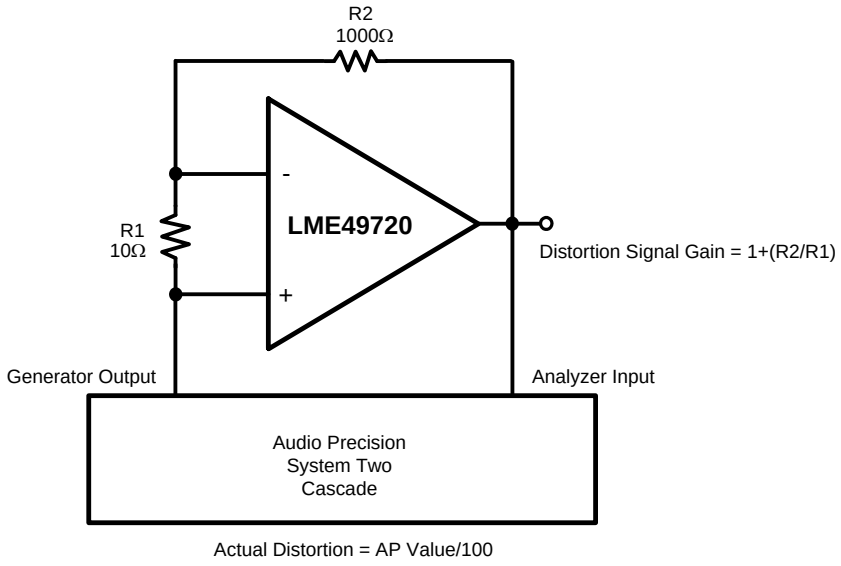
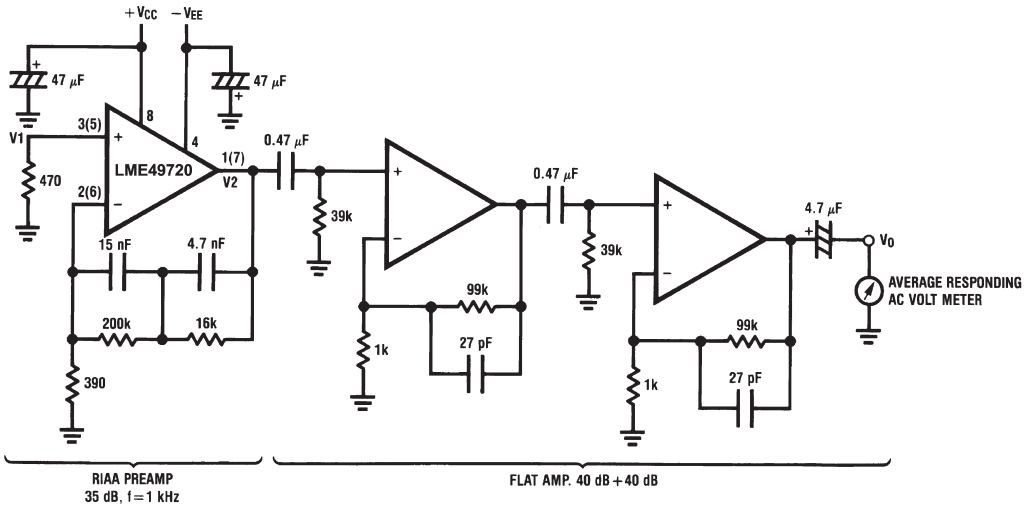


Figure 109. THD+N and IMD Distortion Test Circuit

Distortion Measurements (continued)



Complete shielding is required to prevent induced pick up from external sources. Always check with oscilloscope for power line noise.
Total Gain: 115 dB @F = 1 kHz
Input Referred Noise Voltage: E_n = V0/560,000 (V)

Figure 110. Noise Measurement Circuit

9 Detailed Description

9.1 Overview

The LME49720 audio operational amplifier delivers superior audio signal amplification for outstanding audio performance.

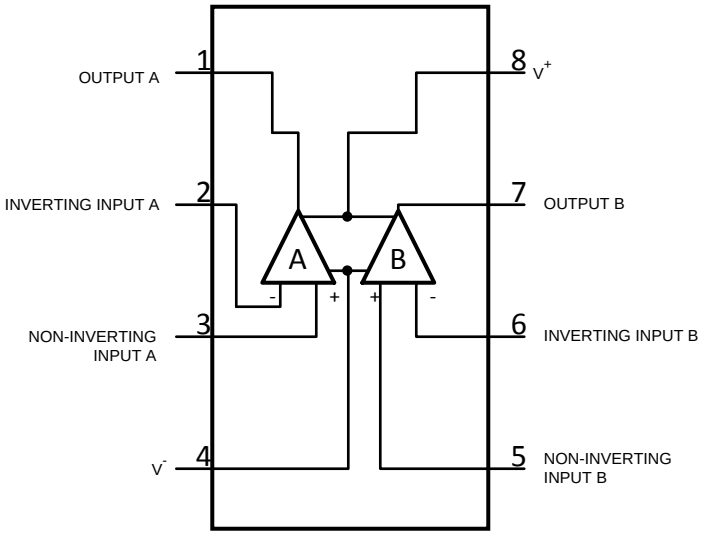
To ensure that the most challenging loads are driven without compromise, the LME49720 has a high slew rate of ±20V/μs and an output current capability of ±26mA. Further, dynamic range is maximized by an output stage that drives 2kΩ loads to within 1V of either power supply voltage and to within 1.4V when driving 600Ω loads.

The LME49720's outstanding CMRR (120dB), PSRR (120dB), and V_{OS} (0.1mV) give the amplifier excellent operational amplifier DC performance.

The LME49720 has a wide supply range of ±2.5V to ±17V. Over this supply range the LME49720's input circuitry maintains excellent common-mode and power supply rejection, as well as maintaining its low input bias current. The LME49720 is unity gain stable. This Audio Operational Amplifier achieves outstanding AC performance while driving complex loads with values as high as 100pF.

The LME49720 is available in 8–lead narrow body SOIC, 8–lead PDIP, and 8–lead TO-99. Demonstration boards are available for each package.

9.2 Functional Block Diagram



9.3 Feature Description

9.3.1 Capacitive Load

The LME49720 is a high speed op amp with excellent phase margin and stability. Capacitive loads up to 100pF will cause little change in the phase characteristics of the amplifiers and are therefore allowable.

Capacitive loads greater than 100pF must be isolated from the output. The most straightforward way to do this is to put a resistor in series with the output. This resistor will also prevent excess power dissipation if the output is accidentally shorted.

9.3.2 Balance Cable Driver

With high peak-to-peak differential output voltage and plenty of low distortion drive current, the LME49720 makes an excellent balanced cable driver. Combining the single-to-differential configuration with a balanced cable driver results in a high performance single-ended input to balanced line driver solution.

Although the LME49720 can drive capacitive loads up to 100pF, cable loads exceeding 100pF can cause instability. For such applications, series resistors are needed on the outputs before the capacitive load.

9.4 Device Functional Modes

This device does not have operation mode.

10 Application and Implementation

NOTE

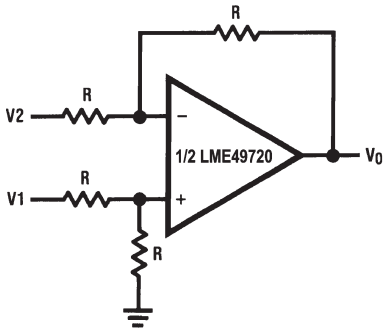
Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

10.1 Application Information

These typical connection diagrams highlight the required external components and system level connections for proper operation of the device. Any design variation can be supported by TI through schematic and layout reviews. Visit e2e.ti.com for design assistance and join the audio amplifier discussion forum for additional information

10.2 Typical Applications

10.2.1 Single Ended Converter



$V_O = V1–V2$

Figure 111. Balanced To Single Ended Converter

10.2.1.1 Design Requirements

For this design example, use the parameters listed in Table 1.

Table 1. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Power Supply	±15
Speaker	2 KΩ

10.2.1.2 Detailed Design Procedure

10.2.1.2.1 Surface Mount Capacitors

Temperature and applied DC voltage influence the actual capacitance of high-K materials. Table 2 shows the relationship between the different types of high-K materials and their associated tolerances, temperature coefficients, and temperature ranges. Notice that a capacitor made with X5R material can lose up to 15% of its capacitance within its working temperature range.

Select high-K ceramic capacitors according to the following rules:

1. Use capacitors made of materials with temperature coefficients of X5R, X7R, or better.
2. Use capacitors with DC voltage ratings of at least twice the application voltage.
3. Choose a capacitance value at least twice the nominal value calculated for the application.

Multiply the nominal value by a factor of 2 for safety. If a 10-µF capacitor is required, use 20µF.

The preceding rules and recommendations apply to capacitors used in connection with this device. The LME49720 cannot meet its performance specifications if the rules and recommendations are not followed.

Table 2. Typical Tolerance and Temperature Coefficient of Capacitance by Material

Material	COG/NPO	X7R	X5R
Typical Tolerance	±5%	±10%	80/–20%
Temperature	±30ppm	±15%	22/–82%
Temperature Range, ºC	–55/125ºC	–55/125ºC	–30/85 ºC

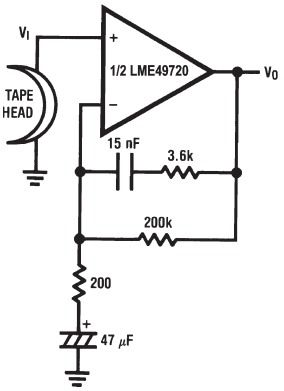
10.2.1.3 Application Curves

For application curves, see the figures listed in Table 3.

Table 3. Table of Graphs

DESCRIPTION	FIGURE NUMBER
THD+N vs Output Power	See Figure 1
THD+N vs Frequency	See Figure 13
Crosstalk vs Frequency	See Figure 36
PSRR vs Frequency	See Figure 58

10.2.2 Other Applications



A_V = 34.5
F = 1 kHz
E_n = 0.38 µV
A Weighted

Figure 112. Nab Preamp

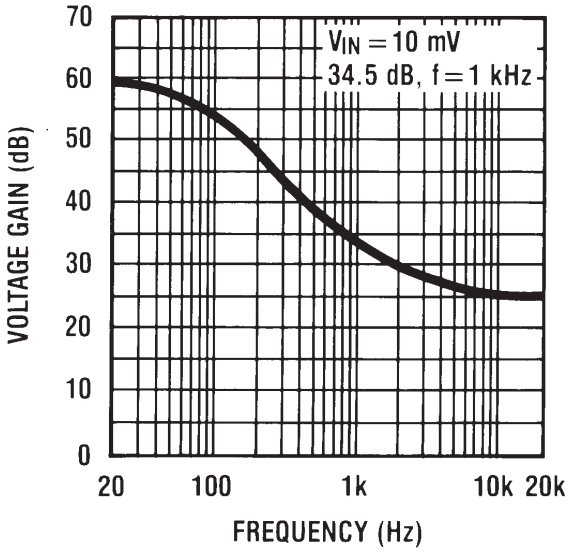
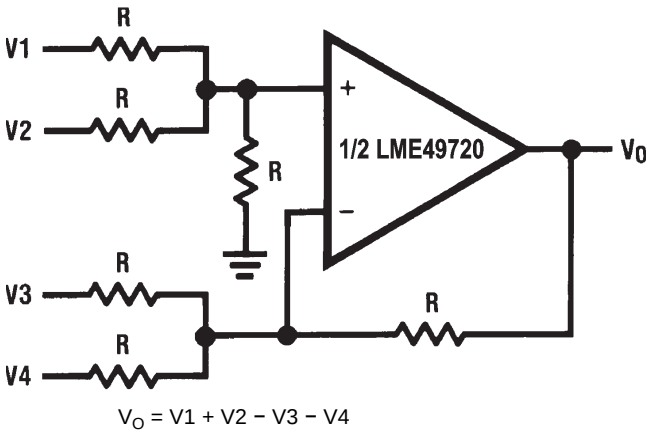
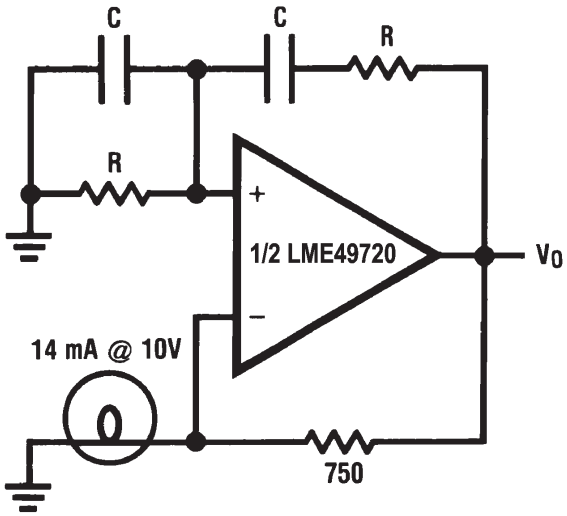


Figure 113. Nab Preamp Voltage Gain vs Frequency



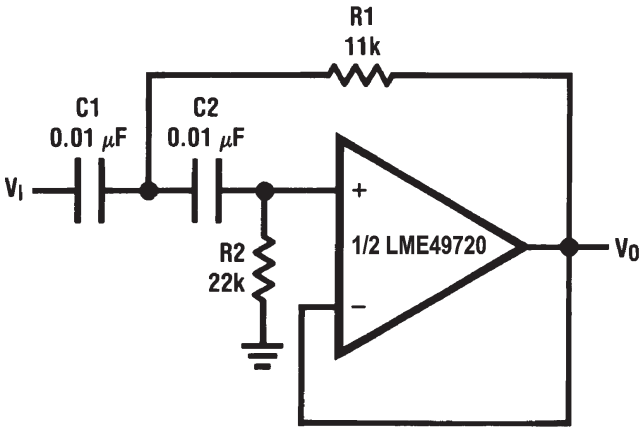
$V_O = V1 + V2 - V3 - V4$

Figure 114. Adder/Subtracter



$$f_o = \frac{1}{2\pi RC}$$

Figure 115. Sine Wave Oscillator



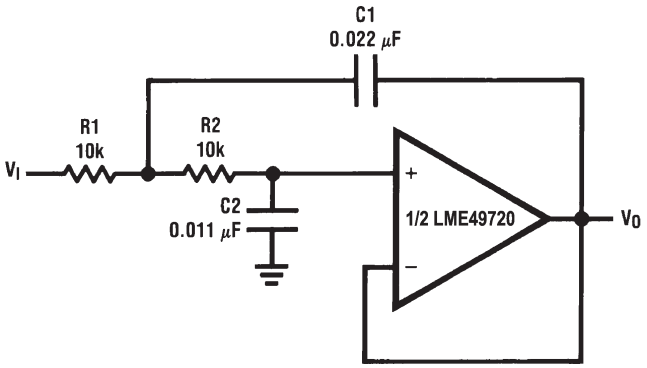
$$\text{if } C1 = C2 = C$$

$$R1 = \frac{\sqrt{2}}{2\omega_o C}$$

$$R2 = 2 \times R1$$

Illustration is f_0 = 1 kHz

Figure 116. Second Order High Pass Filter (Butterworth)



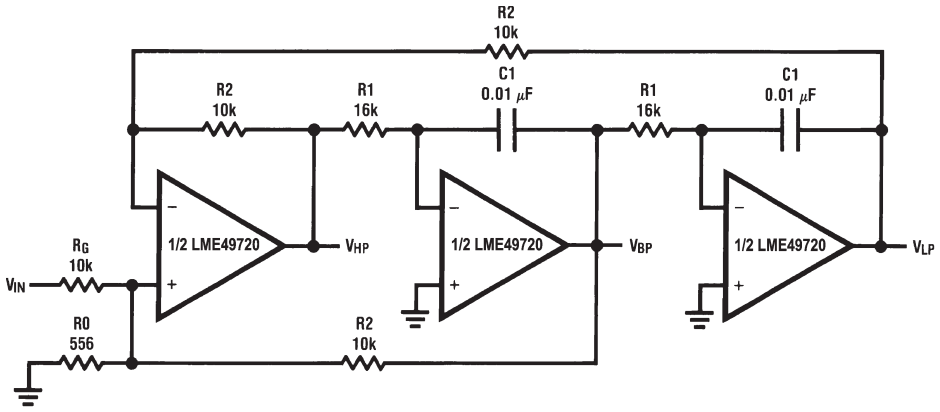
$$\text{if } R1 = R2 = R$$

$$C1 = \frac{\sqrt{2}}{\omega_o R}$$

$$C2 = \frac{C1}{2}$$

Illustration is f_0 = 1 kHz

Figure 117. Second Order Low Pass Filter (Butterworth)



$$f_0 = \frac{1}{2\pi C1R1}, Q = \frac{1}{2}\left(1 + \frac{R2}{R0} + \frac{R2}{RG}\right), A_{BP} = QA_{LP} = QA_{LH} = \frac{R2}{RG}$$

Illustration is f_0 = 1 kHz, Q = 10, A_{BP} = 1

Figure 118. State Variable Filter

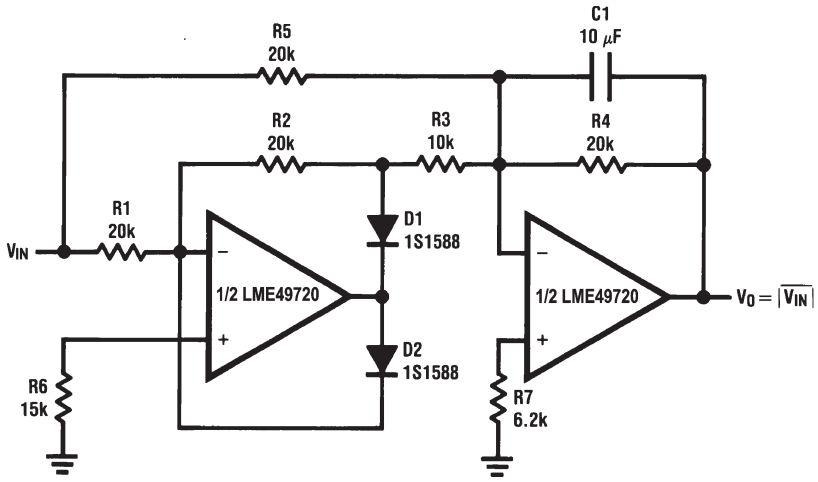


Figure 119. AC/DC Converter

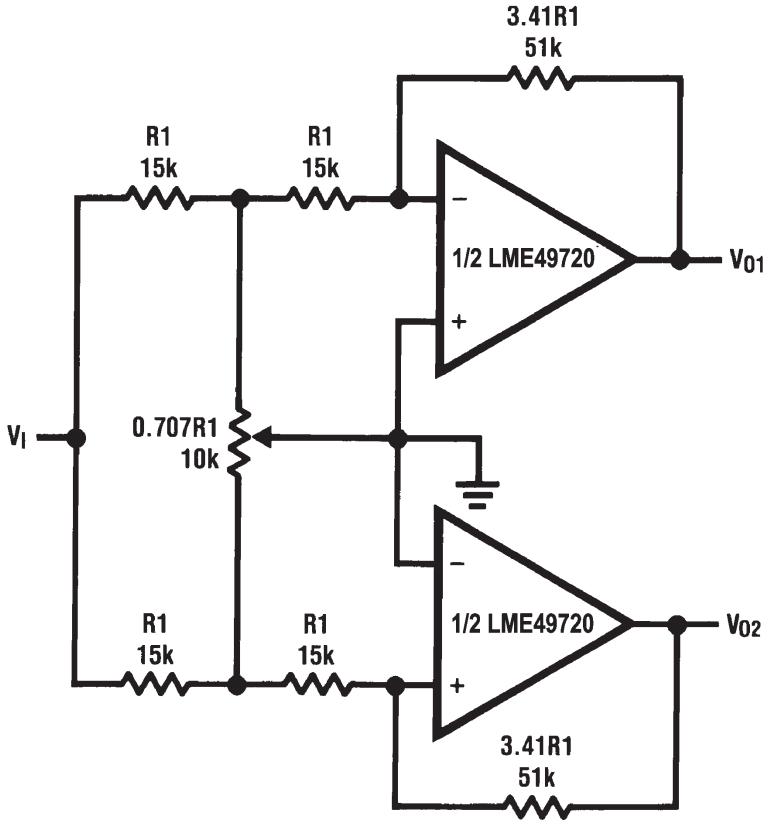


Figure 120. 2 Channel Panning Circuit (Pan Pot)

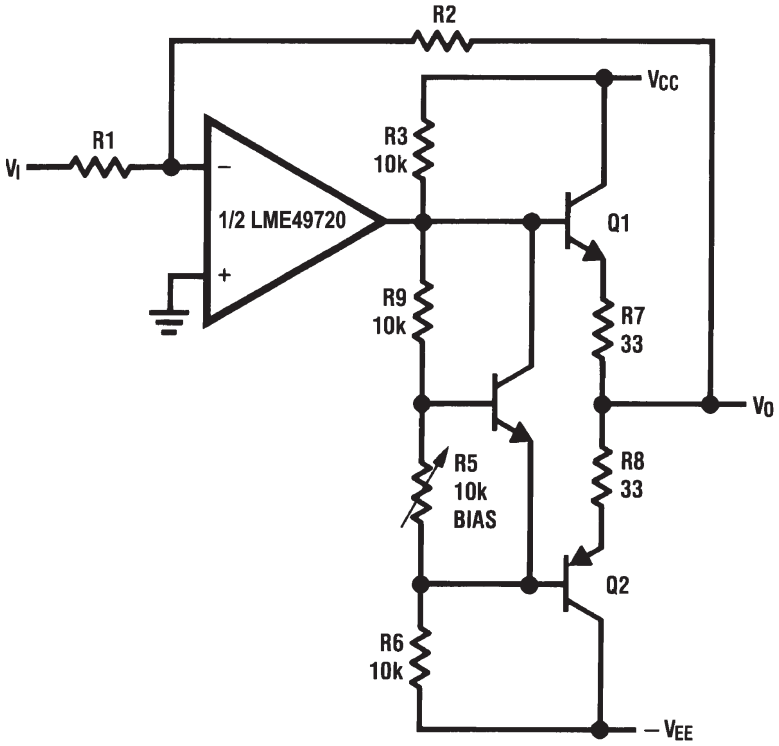
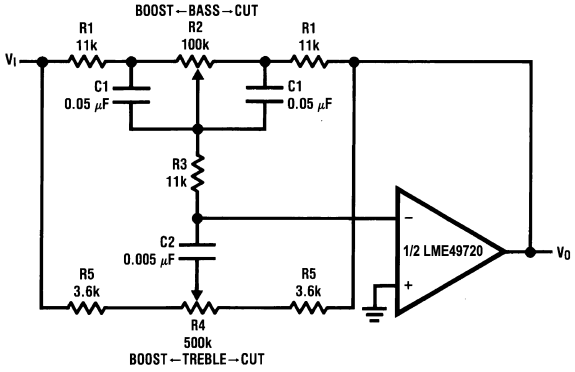


Figure 121. Line Driver



$$f_L = \frac{1}{2\pi R2C1},\ f_{LB} = \frac{1}{2\pi R1C1}$$

$$f_H = \frac{1}{2\pi R5C2},\ f_{HB} = \frac{1}{2\pi(R1 + R5 + 2R3)C2}$$

Illustration is:

f_L = 32 Hz, f_{LB} = 320 Hz

f_H =11 kHz, f_{HB} = 1.1 kHz

Figure 122. Tone Control

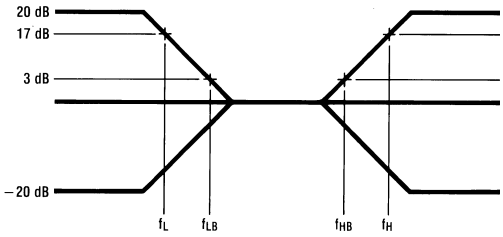
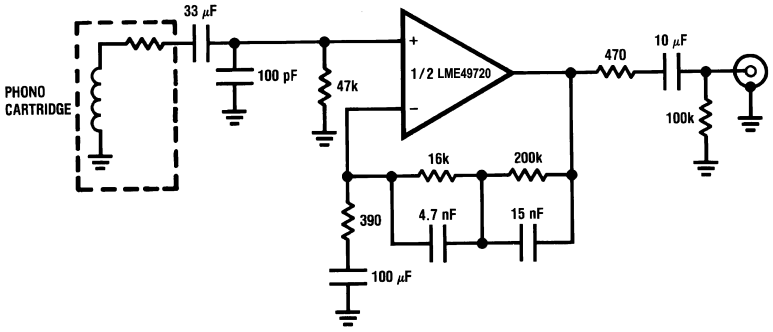
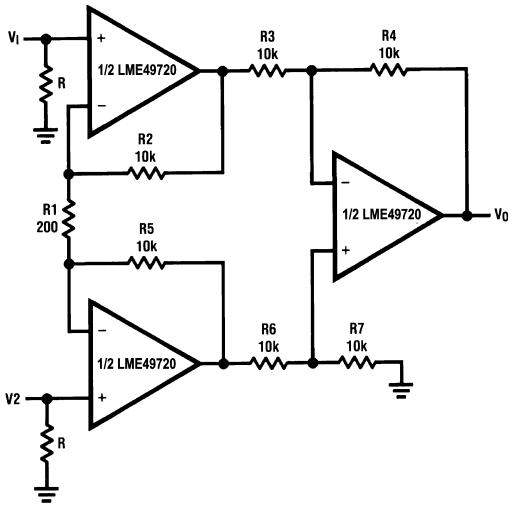


Figure 123. RIAA Preamp Behavior



A_v = 35 dB
E_n = 0.33 µV
S/N = 90 dB
f = 1 kHz
A Weighted
A Weighted, V_{IN} = 10 mV
@f = 1 kHz

Figure 124. RIAA Preamp



If R2 = R5, R3 = R6, R4 = R7

$$V0 = \left(1 + \frac{2R2}{R1}\right)\frac{R4}{R3}(V2 - V1)$$

Illustration is:

V0 = 101(V2 − V1)

Figure 125. Balanced Input Mic Amp

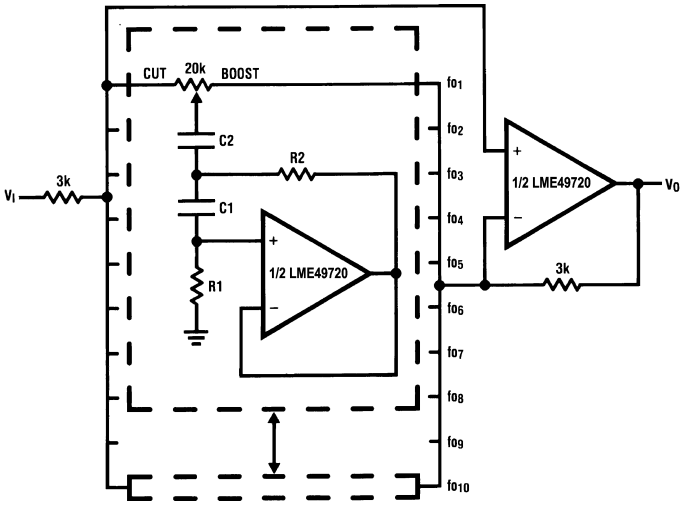


Figure 126. 10 Band Graphic Equalizer

Table 4. Typical Values for Band Graphic Equalizer

fo (Hz)	C_1	C_2	R_1	R_2
32	0.12µF	4.7µF	75kΩ	500Ω
64	0.056µF	3.3µF	68kΩ	510Ω
125	0.033µF	1.5µF	62kΩ	510Ω
250	0.015µF	0.82µF	68kΩ	470Ω
500	8200pF	0.39µF	62kΩ	470Ω
1k	3900pF	0.22µF	68kΩ	470Ω
2k	2000pF	0.1µF	68kΩ	470Ω
4k	1100pF	0.056µF	62kΩ	470Ω
8k	510pF	0.022µF	68kΩ	510Ω
16k	330pF	0.012µF	51kΩ	510Ω

11 Power Supply Recommendations

The LME49720 is designed to operate a power supply from ±2.5V to ±17V. Therefore, the output voltage range of the power supply must be within this range. The current capability of upper power must not exceed the maximum current limit of the power switch.

11.1 Power Supply Decoupling Capacitors

The LME49720 requires adequate power supply decoupling to ensure a low total harmonic distortion (THD). Place a low equivalent-series-resistance (ESR) ceramic capacitor, typically 0.1 µF, within 2 mm of the V+ and V- pins. This choice of capacitor and placement helps with higher frequency transients, spikes, or digital hash on the line. In addition to the 0.1 µF ceramic capacitor, it is recommended to place a 2.2 µF to 10 µF capacitor on the V+ and V- pins. This larger capacitor acts as a charge reservoir, providing energy faster than the board supply, thus helping to prevent any droop in the supply voltage.

12 Layout

12.1 Layout Guidelines

12.1.1 Component Placement

Place all the external components close to the device. Placing the decoupling capacitors as close as possible to the device is important for low total harmonic distortion (THD). Any resistance or inductance in the trace between the device and the capacitor can cause a loss in efficiency.

12.2 Layout Example

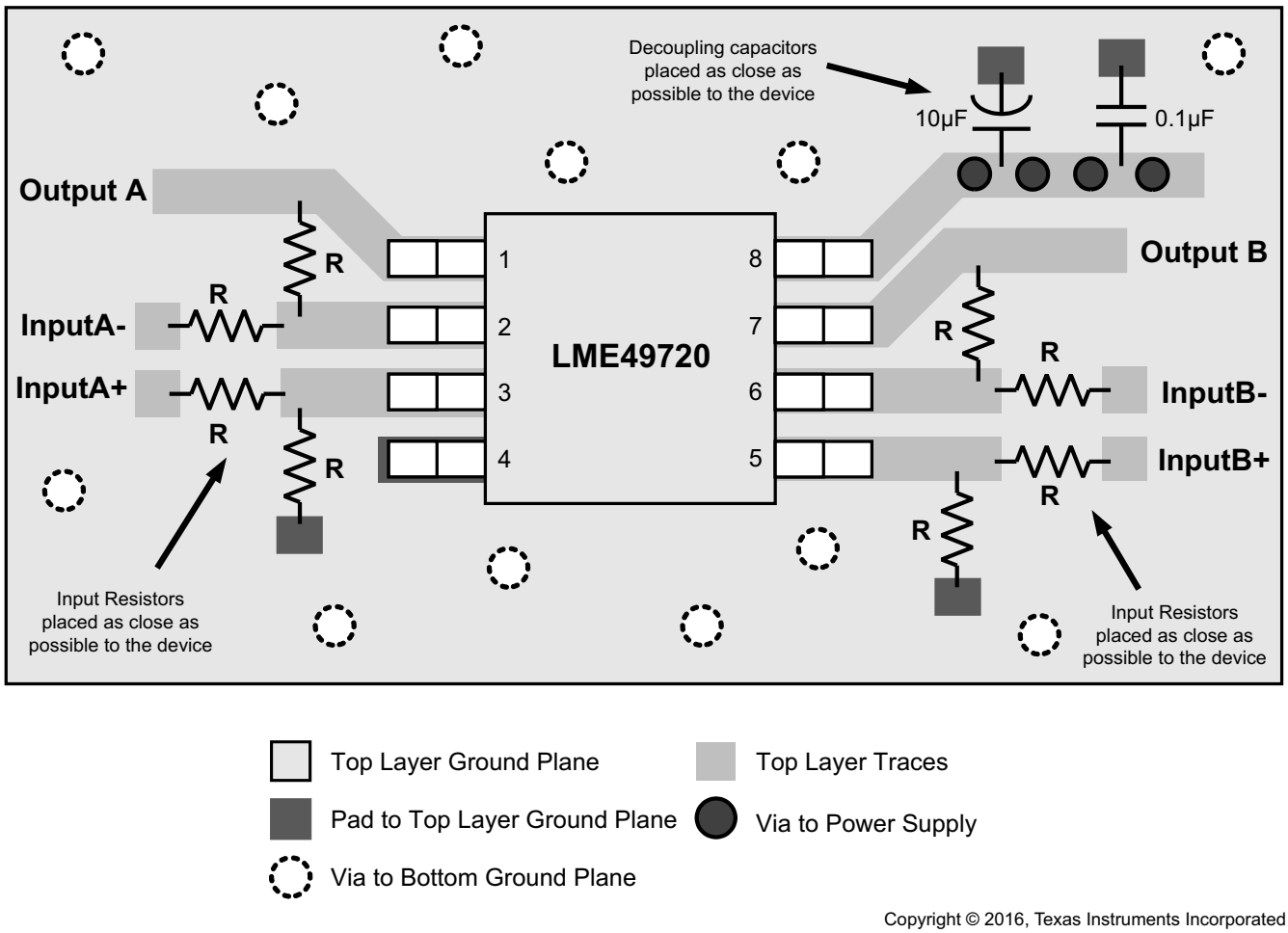


Figure 127. LME49720SOIC Layout Example

Layout Example (continued)

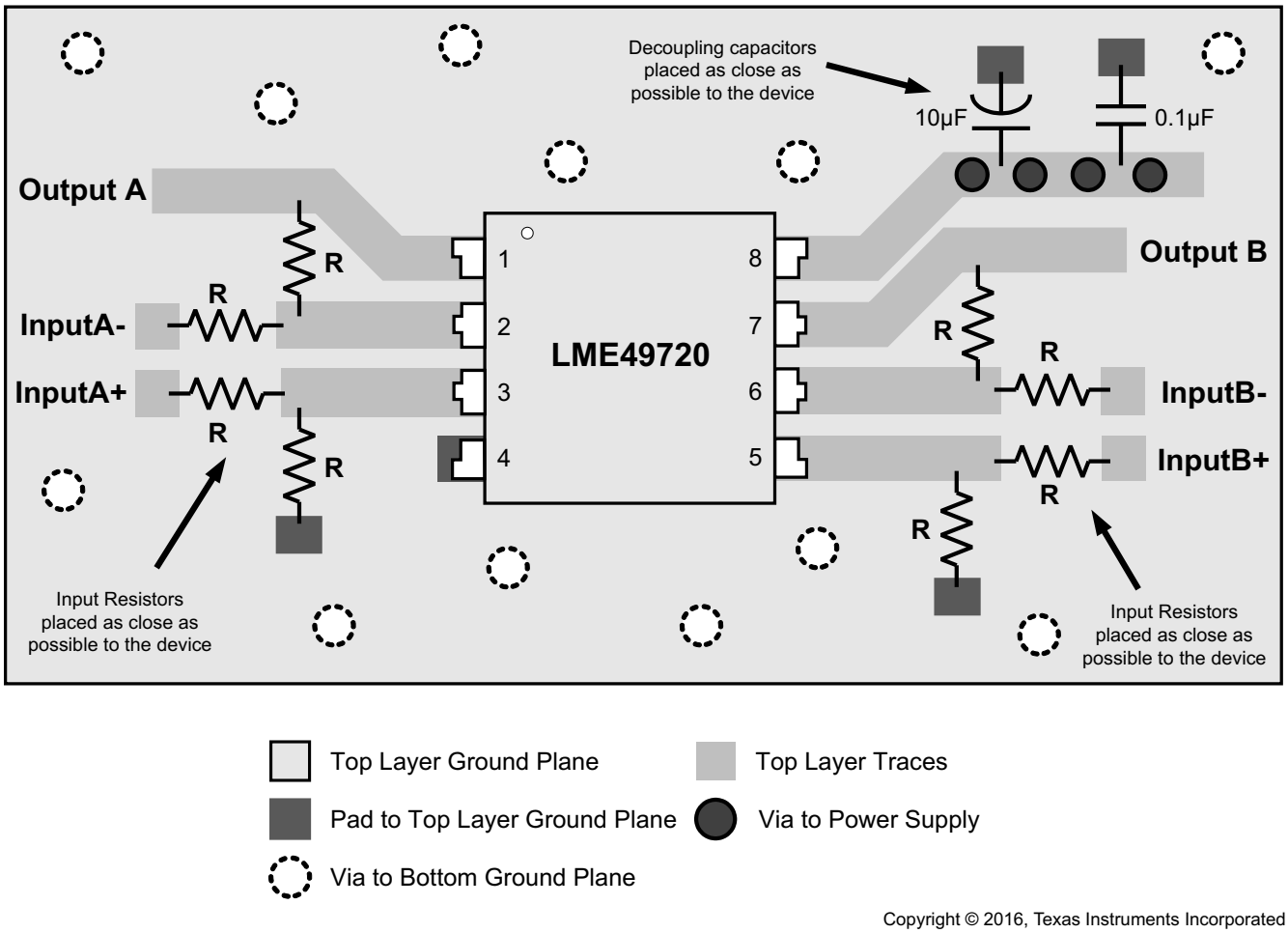


Figure 128. LME49720PDIP Layout Example

Layout Example (continued)

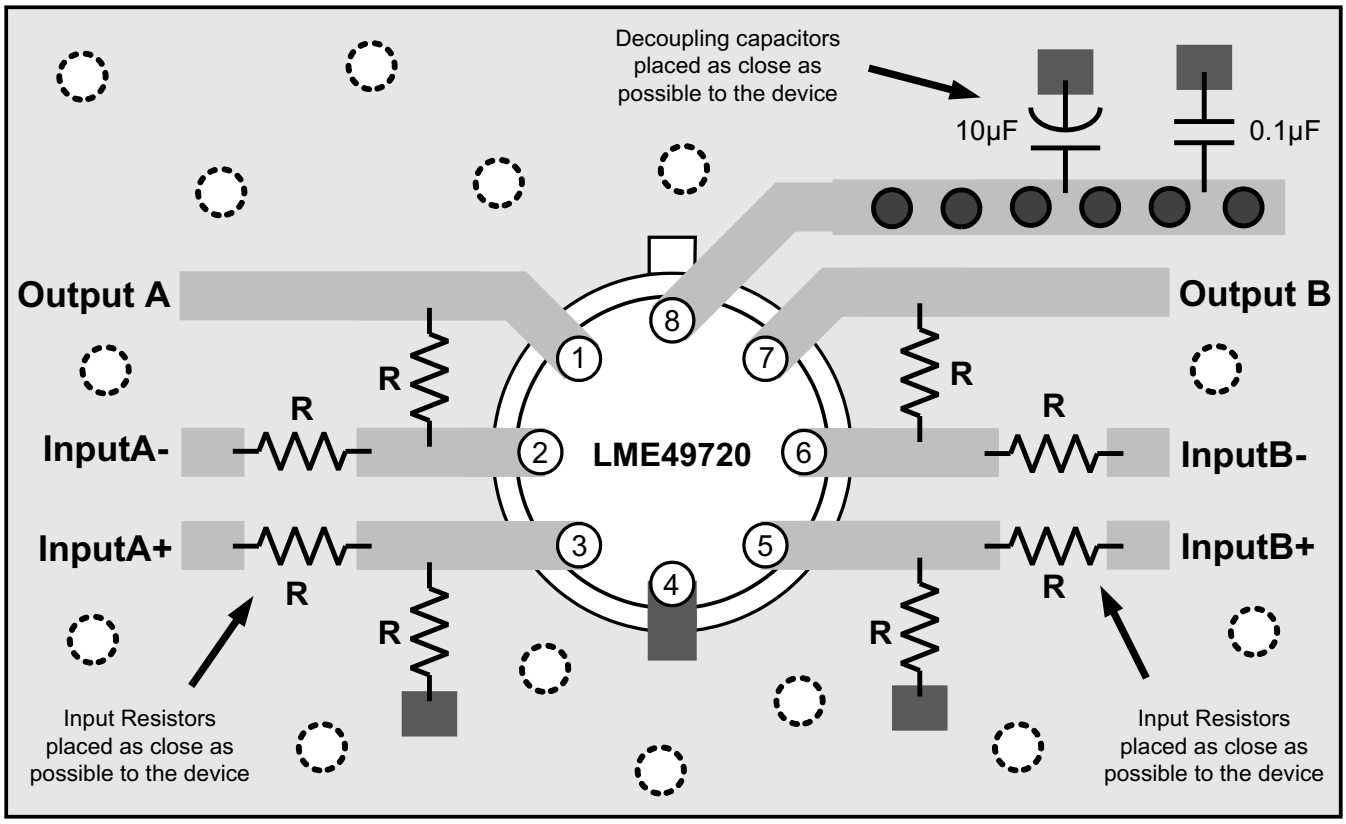


Figure 129. LME49720TO-99 Layout Example

13 Device and Documentation Support

13.1 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

13.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

13.3 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

13.4 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

13.5 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

14 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LME49720MAX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	L49720 MA	Samples
LME49720NA/NOPB	ACTIVE	PDIP	P	8	40	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 85	LME 49720NA	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

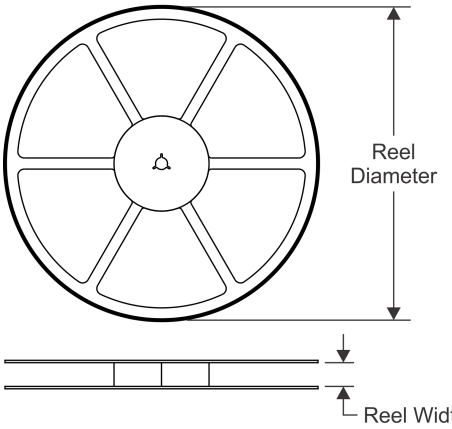
(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

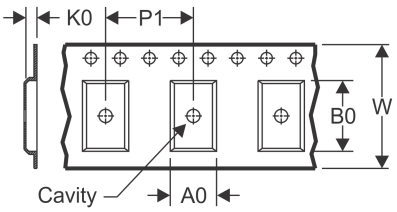
(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

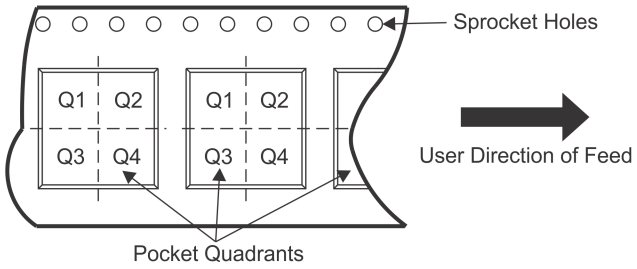


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

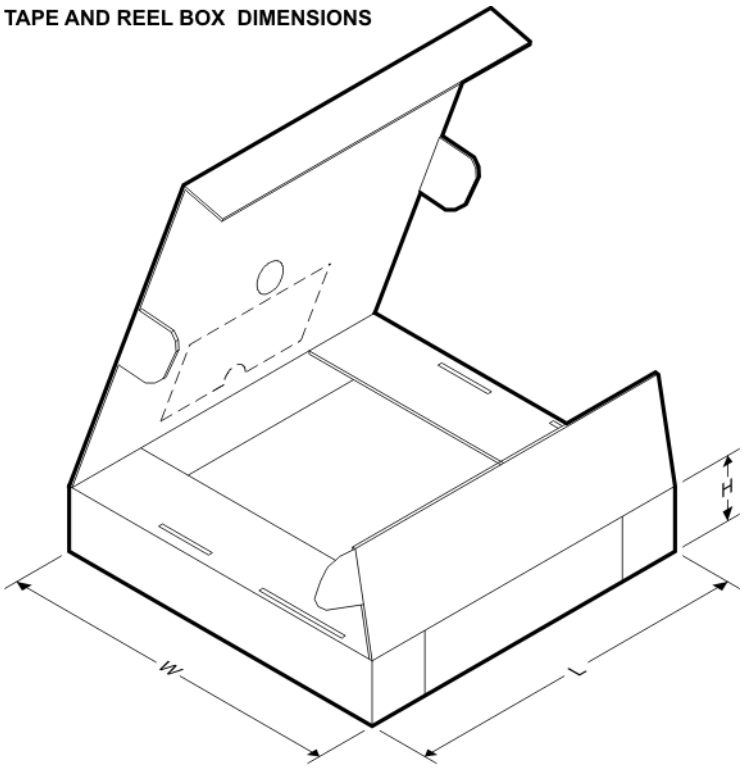
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LME49720MAX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1

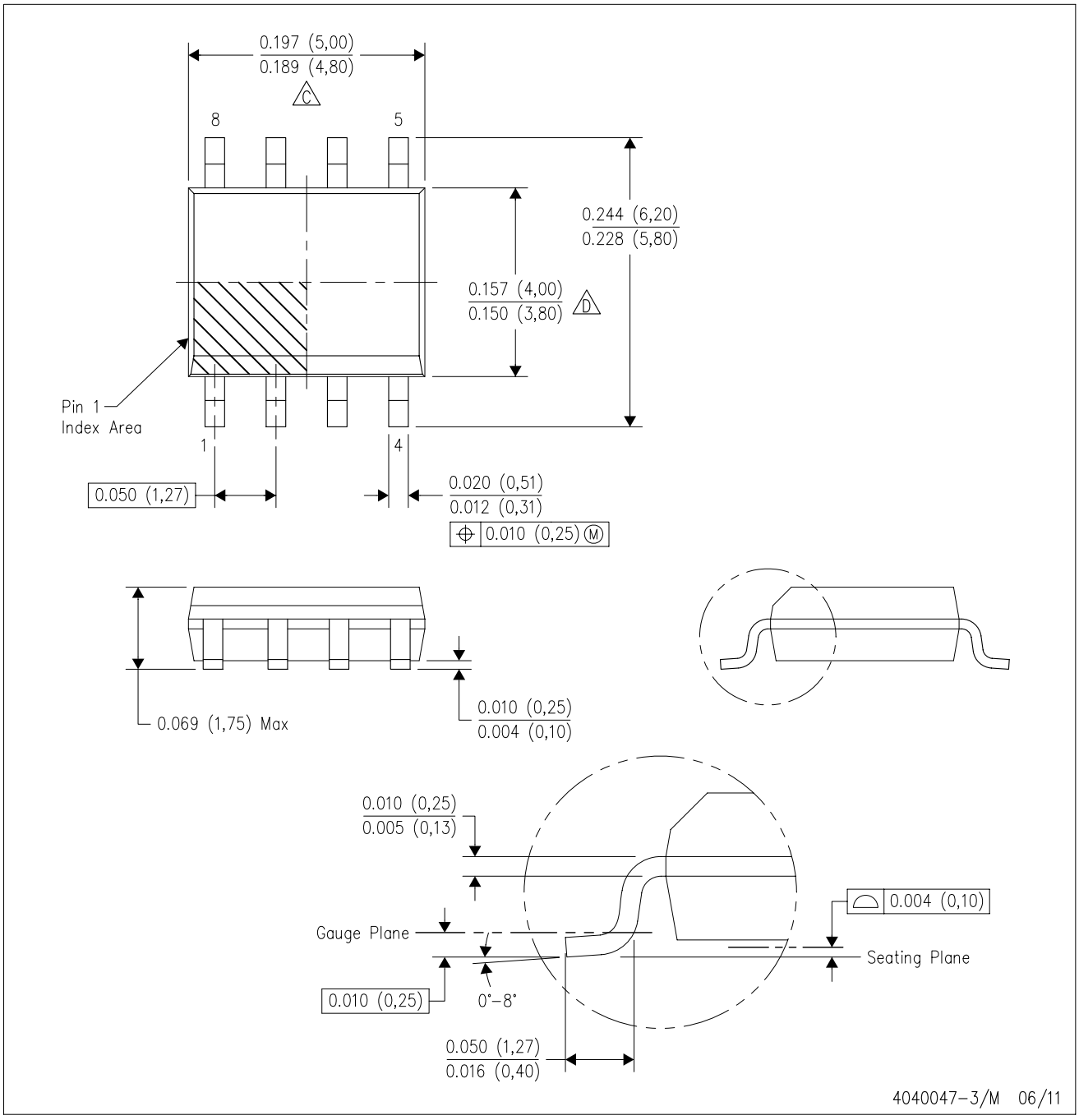
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

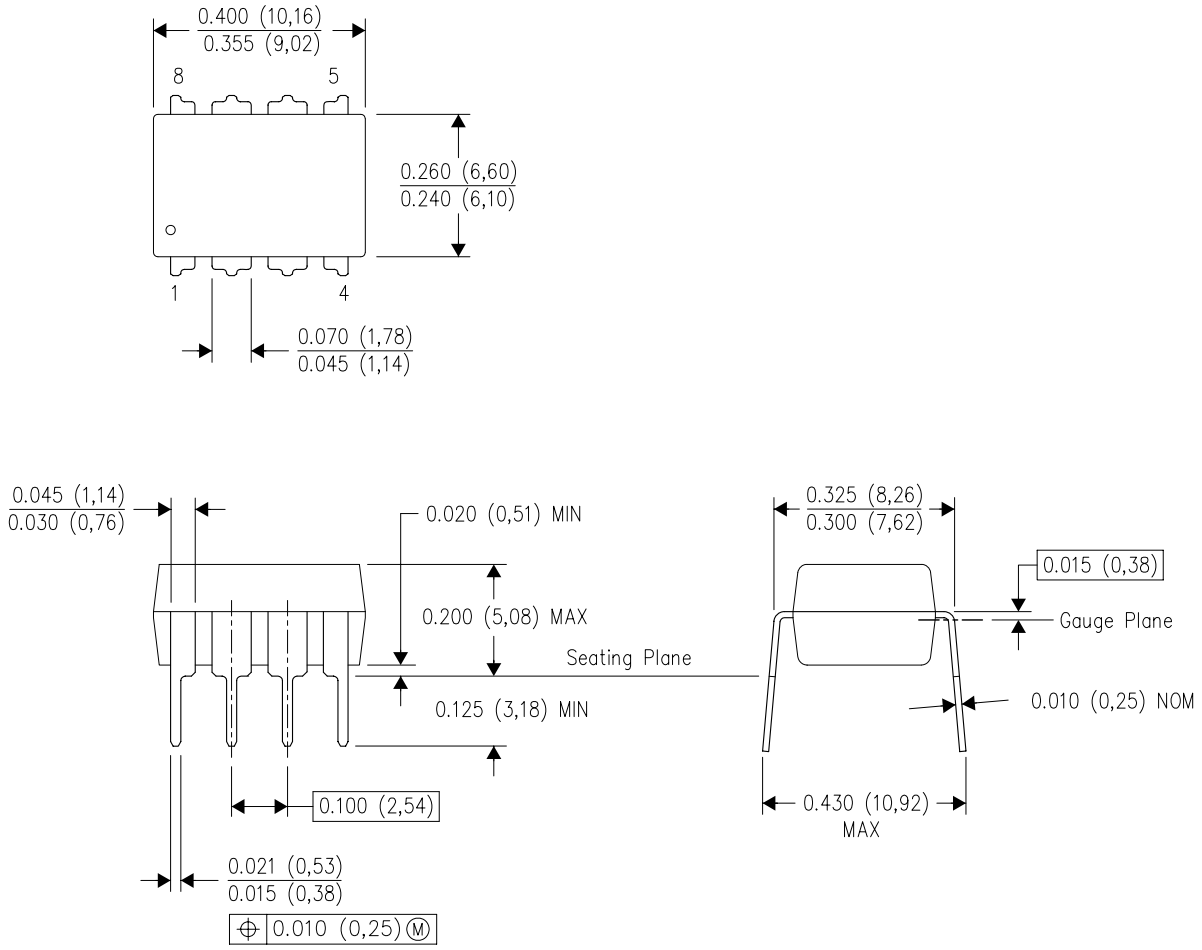
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LME49720MAX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
E. Reference JEDEC MS–012 variation AA.

P (R–PDIP–T8) PLASTIC DUAL–IN–LINE PACKAGE



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS–001 variation BA.

IMPORTANT NOTICE

Texas Instruments Incorporated (TI) reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete.

TI's published terms of sale for semiconductor products (http://www.ti.com/sc/docs/stdterms.htm) apply to the sale of packaged integrated circuit products that TI has qualified and released to market. Additional terms may apply to the use or sale of other types of TI products and services.

Reproduction of significant portions of TI information in TI data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such reproduced documentation. Information of third parties may be subject to additional restrictions. Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyers and others who are developing systems that incorporate TI products (collectively, "Designers") understand and agree that Designers remain responsible for using their independent analysis, evaluation and judgment in designing their applications and that Designers have full and exclusive responsibility to assure the safety of Designers' applications and compliance of their applications (and of all TI products used in or for Designers' applications) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to their applications, Designer has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any applications that include TI products, Designer will thoroughly test such applications and the functionality of such TI products as used in such applications.

TI's provision of technical, application or other design advice, quality characterization, reliability data or other services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using TI Resources in any way, Designer (individually or, if Designer is acting on behalf of a company, Designer's company) agrees to use any particular TI Resource solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

Designer is authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY DESIGNER AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

Unless TI has explicitly designated an individual product as meeting the requirements of a particular industry standard (e.g., ISO/TS 16949 and ISO 26262), TI is not responsible for any failure to meet such industry standard requirements.

Where TI specifically promotes products as facilitating functional safety or as compliant with industry functional safety standards, such products are intended to help enable customers to design and create their own applications that meet applicable functional safety standards and requirements. Using products in an application does not by itself establish any safety features in the application. Designers must ensure compliance with safety-related requirements and standards applicable to their applications. Designer may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

TI may expressly designate certain products as completing a particular qualification (e.g., Q100, Military Grade, or Enhanced Product). Designers agree that it has the necessary expertise to select the product with the appropriate qualification designation for their applications and that proper product selection is at Designers' own risk. Designers are solely responsible for compliance with all legal and regulatory requirements in connection with such selection.

Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer's non-compliance with the terms and provisions of this Notice.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265