August 1999

LMC6042 CMOS Dual Micropower Operational Amplifier

General Description

Ultra-low power consumption and low input-leakage current are the hallmarks of the LMC6042. Providing input currents of only 2 fA typical, the LMC6042 can operate from a single supply, has output swing extending to each supply rail, and an input voltage range that includes ground.

The LMC6042 is ideal for use in systems requiring ultra-low power consumption. In addition, the insensitivity to latch-up, high output drive, and output swing to ground without requiring external pull-down resistors make it ideal for single-supply battery-powered systems.

Other applications for the LMC6042 include bar code reader amplifiers, magnetic and electric field detectors, and hand-held electrometers.

This device is built with National's advanced Double-Poly Silicon-Gate CMOS process.

See the LMC6041 for a single, and the LMC6044 for a quad amplifier with these features.

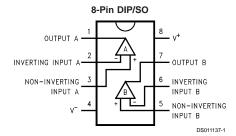
Features

- Low supply current: 10 µA/Amp (typ)
- Operates from 4.5V to 15V single supply
- Ultra low input current: 2 fA (typ)
- Rail-to-rail output swing
- Input common-mode range includes ground

Applications

- Battery monitoring and power conditioning
- Photodiode and infrared detector preamplifier
- Silicon based transducer systems
- Hand-held analytic instruments
- pH probe buffer amplifier
- Fire and smoke detection systems
- Charge amplifier for piezoelectric transducers

Connection Diagram



Ordering Information

Package	Temperature Range Industrial -40°C to +85°C	NSC Drawing	Transport Media
8-Pin	LMC6042AIM	M08A	Rail
Small Outline	LMC6042IM		Tape and Reel
8-Pin	LMC6042AIN	N08E	Rail
Molded DIP	LMC6042IN		

Absolute Maximum Ratings (Note 1)

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

Differential Input Voltage ±Supply Voltage Supply Voltage (V⁺ - V⁻) 16V Output Short Circuit to V+ (Note 12) Output Short Circuit to V-(Note 2) Lead Temperature (Soldering, 10 seconds) 260°C Current at Input Pin ±5 mA Current at Output Pin ±18 mA Current at Power Supply Pin 35 mA Power Dissipation (Note 3)

-65°C to +150°C Storage Temperature Range Junction Temperature (Note 3) 110°C 500V ESD Tolerance (Note 4) Voltage at Input/Output Pin $(V^{+}) + 0.3V, (V^{-}) - 0.3V$

Operating Ratings

Temperature Range

LMC6042AI, LMC6042I $-40^{\circ}\text{C} \le \text{T}_{\text{J}} \le +85^{\circ}\text{C}$ Supply Voltage $4.5V \leq V^+ \leq 15.5V$ Power Dissipation (Note 10)

Thermal Resistance (θ_{JA}), (Note 11)

8-Pin DIP 101°C/W 165°C/W 8-Pin SO

Electrical Characteristics

Unless otherwise spec ified, all limits guaranteed for $T_A = T_J = 25^{\circ}C$. **Boldface** limits apply at the temperature extremes. $V^+ = 5V$, $V^- = 0V$, $V_{CM} = 1.5V$, $V_O = V^+/2$ and $R_L > 1M$ unless otherwise specified.

				Typical	LMC6042AI	LMC6042I	Units
Symbol	Parameter	Conditions		(Note 5)	Limit	Limit	(Limit)
					(Note 6)	(Note 6)	
Vos	Input Offset Voltage			1	3	6	mV
					3.3	6.3	Max
TCVos	Input Offset Voltage			1.3			μV/°C
	Average Drift						
I _B	Input Bias Current			0.002	4	4	pA (Max)
Ios	Input Offset Current			0.001	2	2	pA (Max)
R _{IN}	Input Resistance			>10			TeraΩ
CMRR	Common Mode	0V ≤ V _{CM} ≤ 12.0V		75	68	62	dB
	Rejection Ratio	V+ = 15V			66	60	Min
+PSRR	Positive Power Supply	5V ≤ V ⁺ ≤ 15V		75	68	62	dB
	Rejection Ratio	V _O = 2.5V			66	60	Min
-PSRR	Negative Power Supply	0V ≤ V ⁻ ≤ −10V		94	84	74	dB
	Rejection Ratio	V _O = 2.5V			83	73	Min
CMR	Input Common-Mode	V ⁺ = 5V and 15V		-0.4	-0.1	-0.1	V
	Voltage Range	For CMRR ≥ 50 dB			0	0	Max
				V+-1.9V	V+- 2.3V	V+- 2.3V	V
					V+- 2.5V	V+- 2.4V	Min
A _V	Large Signal	$R_L = 100 \text{ k}\Omega \text{ (Note 7)}$	Sourcing	1000	400	300	V/mV
	Voltage Gain				300	200	Min
			Sinking	500	180	90	V/mV
					120	70	Min
		$R_L = 25 \text{ k}\Omega \text{ (Note 7)}$	Sourcing	1000	200	100	V/mV
					160	80	Min
			Sinking	250	100	50	V/mV
					60	40	Min

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Electrical Characteristics (Continued)

Unless otherwise spec ified, all limits guaranteed for $T_A = T_J = 25^{\circ}C$. **Boldface** limits apply at the temperature extremes. $V^+ = 5V$, $V^- = 0V$, $V_{CM} = 1.5V$, $V_O = V^+/2$ and $R_L > 1M$ unless otherwise specified.

			Typical	LMC6042AI	LMC6042I	Units
Symbol	Parameter	Conditions	(Note 5)	Limit	Limit	(Limit)
				(Note 6)	(Note 6)	
Vo	Output Swing	V+ = 5V	4.987	4.970	4.940	V
		$R_L = 100 \text{ k}\Omega \text{ to V}^+/2$		4.950	4.910	Min
			0.004	0.030	0.060	V
				0.050	0.090	Max
		V+ = 5V	4.980	4.920	4.870	V
		$R_L = 25 \text{ k}\Omega \text{ to V}^+/2$		4.870	4.820	Min
			0.010	0.080	0.130	V
				0.130	0.180	Max
		V+ = 15V	14.970	14.920	14.880	V
		$R_{L} = 100 \text{ k}\Omega \text{ to V}^{+}/2$		14.880	14.820	Min
			0.007	0.030	0.060	V
				0.050	0.090	Max
		V ⁺ = 15V	14.950	14.900	14.850	V
		$R_L = 25 \text{ k}\Omega \text{ to V}^+/2$		14.850	14.800	Min
			0.022	0.100	0.150	V
				0.150	0.200	Max
I _{SC}	Output Current	Sourcing, V _O = 0V	22	16	13	mA
	V ⁺ = 5V			10	8	Min
		Sinking, V _O = 5V	21	16	13	mA
				8	8	Min
I _{sc}	Output Current	Sourcing, V _O = 0V	40	15	15	mA
	V ⁺ = 15V			10	10	Min
		Sinking, V _O = 13V	39	24	21	mA
		(Note 12)		8	8	Min
Is	Supply Current	Both Amplifiers	20	34	45	μA
		V _O = 1.5V		39	50	Max
		Both Amplifiers	26	44	56	μA
		V ⁺ = 15V		51	65	Max

AC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for $T_A = T_J = 25^{\circ}\text{C}$. **Boldface** limits apply at the temperature extremes. $V^+ = 5V$, $V^- = 0V$, $V_{CM} = 1.5V$, $V_O = V^+/2$ and $R_L > 1M$ unless otherwise specified.

			Тур	LMC6042AI	LMC6042I	Units
Symbol	Parameter	Conditions	(Note 5)	Limit	Limit	(Limit)
				(Note 6)	(Note 6)	
SR	Slew Rate	(Note 8)	0.02	0.015	0.010	V/µs
				0.010	0.007	Min
GBW	Gain-Bandwidth Product		100			kHz
φ _m	Phase Margin		60			Deg
	Amp-to-Amp Isolation	(Note 9)	115			dB
e _n	Input-Referred	f = 1 kHz	83			nV∕t√ Hz
	Voltage Noise					
i _n	Input-Referred	f = 1 kHz	0.0002			pA/√ Hz
	Current Noise					

AC Electrical Characteristics (Continued)

Unless otherwise specified, all limits guaranteed for $T_A = T_J = 25^{\circ}\text{C}$. **Boldface** limits apply at the temperature extremes. $V^+ = 5V, \, V^- = 0V, \, V_{CM} = 1.5V, \, V_O = V^+/2$ and $R_L > 1M$ unless otherwise specified.

Symbol	Parameter	Conditions	Typ (Note 5)	LMC6042AI Limit (Note 6)	LMC6042I Limit (Note 6)	Units (Limit)
T.H.D.	Total Harmonic Distortion	$f = 1 \text{ kHz}, A_V = -5$ $R_L = 100 \text{ k}\Omega, V_O = 2 \text{ V}_{PP}$	0.01			%
		±5V Supply				

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Conditions indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed.

Note 2: Applies to both single-supply operation. Continuous short circuit operation at elevated ambient temperature can result in exceeding the maximum allowed junction temperature of 110°C. Output currents in excess of ±30 mA over long term may adversely affect reliability.

Note 3: The maximum power dissipation is a function of $T_{J(Max)}$, θ_{JA} , and T_A . The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(Max)} - T_A)/\theta_{JA}$.

Note 4: Human body model, 1.5 k Ω in series with 100 pF.

Note 5: Typical values represent the most likely parametric norm.

Note 6: All limits are guaranteed at room temperature (standard type face) or at operating temperature extremes (bold face type).

Note 7: V^+ = 15V, V_{CM} = 7.5V and R_L connected to 7.5V. For Sourcing tests, 7.5V $\leq V_O \leq$ 11.5V. For Sinking tests, 2.5V $\leq V_O \leq$ 7.5V.

Note 8: V+ = 15V. Connected as Voltage Follower with 10V step input. Number specified is the slower of the positive and negative slew rates.

Note 9: Input referred V+ = 15V and R_L = 100 k Ω connected to V+/2. Each amp excited in turn with 100 Hz to produce V_O = 12 V_{PP} .

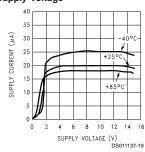
Note 10: For operating at elevated temperatures the device must be derated based on the thermal resistance θ_{JA} with $P_D = (T_J - T_A)/\theta_{JA}$.

Note 11: All numbers apply for packages soldered directly into a PC board.

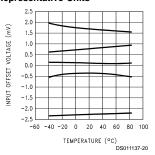
Note 12: Do not connect output to V+when V+ is greater than 13V or reliability may be adversely affected.

Typical Performance Characteristics $V_S = \pm 7.5 V$, $T_A = 25 ^{\circ} C$ unless otherwise specified

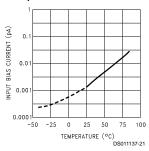
Supply Current vs Supply Voltage



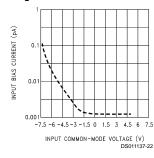
Offset Voltage vs Temperature of Five Representative Units



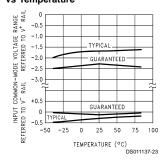
Input Bias Current vs Temperature



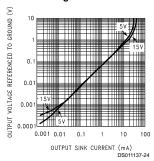
Input Bias Current vs Input Common-Mode Voltage



Input Common-Mode Voltage Range vs Temperature

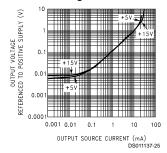


Output Characteristics Current Sinking

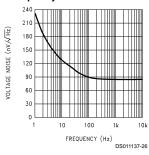


Typical Performance Characteristics $V_S = \pm 7.5 \text{V}$, $T_A = 25^{\circ}\text{C}$ unless otherwise specified (Continued)

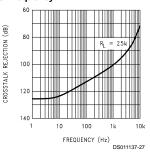
Output Characteristics Current Sourcing



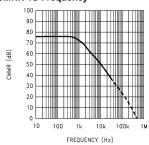
Input Voltage Noise vs Frequency



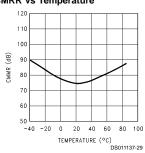
Crosstalk Rejection vs Frequency



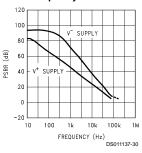
CMRR vs Frequency



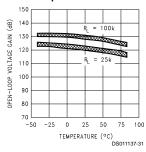
CMRR vs Temperature



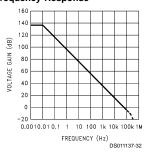
Power Supply Rejection Ratio vs Frequency



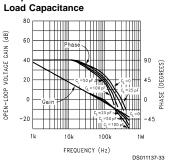
Open-Loop Voltage Gain vs Temperature



Open-Loop Frequency Response

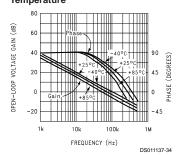


Gain and Phase Responses vs

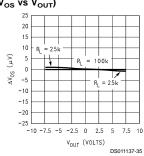


Typical Performance Characteristics $V_S = \pm 7.5V$, $T_A = 25^{\circ}C$ unless otherwise specified (Continued)

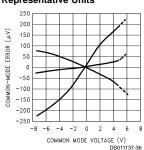
Gain and Phase Response vs Temperature



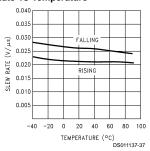
Gain Error (Vos vs Vout)



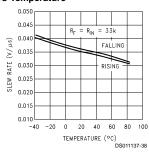
Common-Mode Error vs Common-Mode Voltage of 3 Representative Units



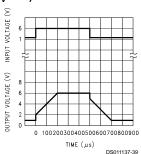
Non-Inverting Slew Rate vs Temperature



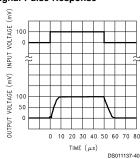
Inverting Slew Rate vs Temperature



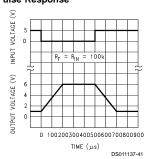
Non-Inverting Large Signal Pulse Response (A_V = +1)



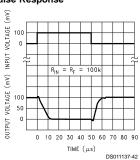
Non-Inverting Small Signal Pulse Response



Inverting Large-Signal Pulse Response

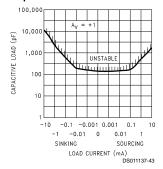


Inverting Small Signal Pulse Response



Typical Performance Characteristics $V_S = \pm 7.5V$, $T_A = 25^{\circ}C$ unless otherwise specified (Continued)

Stability vs Capacitive Load



Applications Hints

AMPLIFIER TOPOLOGY

The LMC6042 incorporates a novel op-amp design topology that enables it to maintain rail-to-rail output swing even when driving a large load. Instead of relying on a push-pull unity gain output buffer stage, the output stage is taken directly from the internal integrator, which provides both low output impedance and large gain. Special feed-forward compensation design techniques are incorporated to maintain stability over a wider range of operating conditions than traditional micropower op-amps. These features make the LMC6042 both easier to design with, and provide higher speed than products typically found in this ultra-low power class.

COMPENSATING FOR INPUT CAPACITANCE

It is quite common to use large values of feedback resistance with amplifiers with ultra-low input curent, like the LMC6042.

Although the LMC6042 is highly stable over a wide range of operating conditions, certain precautions must be met to achieve the desired pulse response when a large feedback resistor is used. Large feedback resistors and even small values of input capacitance, due to transducers, photodiodes, and circuit board parasitics, reduce phase margins.

When high input impedances are demanded, guarding of the LMC6042 is suggested. Guarding input lines will not only reduce leakage, but lowers stray input capacitance as well. (See Printed-Circuit-Board Layout for High Impedance Work).

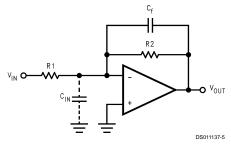
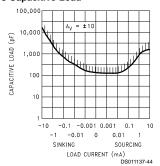


FIGURE 1. Cancelling the Effect of Input Capacitance

Stability vs Capacitive Load



The effect of input capacitance can be compensated for by adding a capacitor. Place a capacitor, C_f , around the feedback resistor (as in *Figure 1*) such that:

$$\frac{1}{2\pi \text{R1 C}_{IN}} \geq \frac{1}{2\pi \text{R2 C}_f}$$

0

$$R1 C_{IN} \le R2 C_f$$

Since it is often difficult to know the exact value of $C_{\rm IN}$, $C_{\rm f}$ can be experimentally adjusted so that the desired pulse response is achieved. Refer to the LMC660 and the LMC662 for a more detailed discussion on compensating for input capacitance.

CAPACITIVE LOAD TOLERANCE

Direct capacitive loading will reduce the phase margin of many op-amps. A pole in the feedback loop is created by the combination of the op-amp's output impedance and the capacitive load. This pole induces phase lag at the unity-gain crossover frequency of the amplifier resulting in either an oscillatory or underdamped pulse response. With a few external components, op amps can easily indirectly drive capacitive loads, as shown in *Figure 2*.

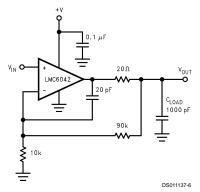


FIGURE 2. LMC6042 Noninverting Gain of 10 Amplifier, Compensated to Handle Capacitive Loads

In the circuit of *Figure 2*, R1 and C1 serve to counteract the loss of phase margin by feeding the high frequency compo-

Applications Hints (Continued)

nent of the output signal back to the amplifier's inverting input, thereby preserving phase margin in the overall feedback loop.

Capacitive load driving capability is enhanced by using a pull up resistor to V $^+$ (Figure~3). Typically a pull up resistor conducting 10 μ A or more will significantly improve capacitive load responses. The value of the pull up resistor must be determined based on the current sinking capability of the amplifier with respect to the desired output swing. Open loop gain of the amplifier can also be affected by the pull up resistor (see Electrical Characteristics).

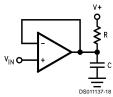


FIGURE 3. Compensating for Large Capacitive Loads with a Pull Up Resistor

PRINTED-CIRCUIT-BOARD LAYOUT FOR HIGH-IMPEDANCE WORK

It is generally recognized that any circuit which must operate with less than 1000 pA of leakage current requires special layout of the PC board. When one wishes to take advantage of the ultra-low bias current of the LMC6042, typically less than 2 fA, it is essential to have an excellent layout. Fortunately, the techniques of obtaining low leakages are quite simple. First, the user must not ignore the surface leakage of the PC board, even though it may sometimes appear acceptably low, because under conditions of high humidity or dust or contamination, the surface leakage will be appreciable.

To minimize the effect of any surface leakage, lay out a ring of foil completely surrounding the LMC6042's inputs and the terminals of capacitors, diodes, conductors, resistors, relay terminals etc. connected to the op-amp's inputs, as in Figure 4. To have a significant effect, guard rings should be placed on both the top and bottom of the PC board. This PC foil must then be connected to a voltage which is at the same voltage as the amplifier inputs, since no leakage current can flow between two points at the same potential. For example, a PC board trace-to-pad resistance of $10^{12}\Omega$, which is normally considered a very large resistance, could leak 5 pA if the trace were a 5V bus adjacent to the pad of the input. This would cause a 100 times degradation from the LMC6042's actual performance. However, if a guard ring is held within 5 mV of the inputs, then even a resistance of $10^{11}\Omega$ would cause only 0.05 pA of leakage current. See Figure 5 for typical connections of guard rings for standard op-amp configurations.

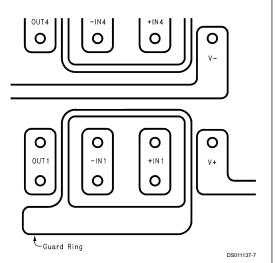
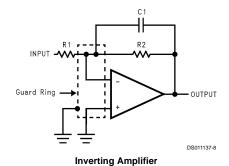


FIGURE 4. Example of Guard Ring in P.C. Board Layout



Guard Ring OUTPUT

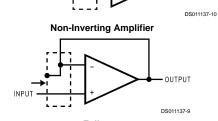
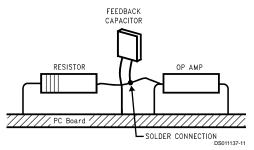


FIGURE 5. Typical Connections of Guard Rings

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Applications Hints (Continued)

The designer should be aware that when it is inappropriate to lay out a PC board for the sake of just a few circuits, there is another technique which is even better than a guard ring on a PC board: Don't insert the amplifier's input pin into the board at all, but bend it up in the air and use only air as an insulator. Air is an excellent insulator. In this case you may have to forego some of the advantages of PC board construction, but the advantages are sometimes well worth the effort of using point-to-point up-in-the-air wiring. See Figure



(Input pins are lifted out of PC board and soldered directly to components All other pins connected to PC board.)

FIGURE 6. Air Wiring

Typical Single-Supply Applications $(V^+ = 5.0 V_{DC})$

The extremely high input impedance, and low power consumption, of the LMC6042 make it ideal for applications that require battery-powered instrumentation amplifiers. Examples of these types of applications are hand-held pH

probes, analytic medical instruments, magnetic field detectors, gas detectors, and silicon based pressure transducers.

The circuit in Figure 7 is recommended for applications where the common-mode input range is relatively low and the differential gain will be in the range of 10 to 1000. This two op-amp instrumentation amplifier features an independent adjustment of the gain and common-mode rejection trim, and a total quiescent supply current of less than 20 $\mu\text{A}.$ To maintain ultra-high input impedance, it is advisable to use ground rings and consider PC board layout an important part of the overall system design (see Printed-Circuit-Board Layout for High Impedance Work). Referring to Figure 7, the input voltages are represented as a common-mode input V_{CM} plus a differential input $\text{V}_{\text{D}}.$

Rejection of the common-mode component of the input is accomplished by making the ratio of R1/R2 equal to R3/R4. So that where.

$$\begin{split} \frac{R3}{R4} &= \frac{R2}{R1} \\ V_{OUT} &= \frac{R4}{R3} \left(1 + \frac{R3}{R4} + \frac{R2 + R3}{R0} \right) V_D \end{split}$$

A suggested design guideline is to minimize the difference of value between R1 through R4. This will often result in improved resistor tempco, amplifier gain, and CMRR over temperature. If RN = R1 = R2 = R3 = R4 then the gain equation can be simplified:

$$V_{OUT} = 2\left(1 + \frac{RN}{R0}\right)V_{D}$$

Due to the "zero-in, zero-out" performance of the LMC6042, and output swing rail-rail, the dynamic range is only limited to the input common-mode range of 0V to $\rm V_S-2.3V,\ worst$ case at room temperature. This feature of the LMC6042 makes it an ideal choice for low-power instrumentation systems

A complete instrumentation amplifier designed for a gain of 100 is shown in *Figure 8*. Provisions have been made for low sensitivity trimming of CMRR and gain.

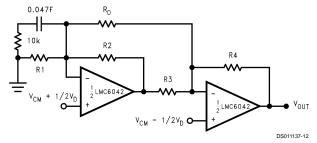


FIGURE 7. Two Op-Amp Instrumentation Amplifier

Typical Single-Supply Applications $(V^+ = 5.0 V_{DC})$ (Continued)

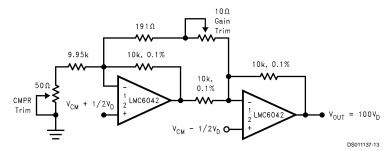


FIGURE 8. Low-Power Two-Op-Amp Instrumentation Amplifier

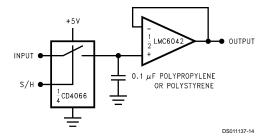


FIGURE 9. Low-Leakage Sample and Hold

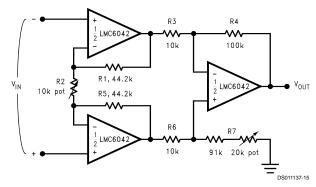


FIGURE 10. Instrumentation Amplifier

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Typical Single-Supply Applications ($V^+ = 5.0 V_{DC}$) (Continued)

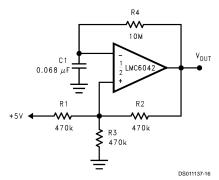


FIGURE 11. 1 Hz Square Wave Oscillator

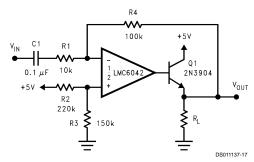
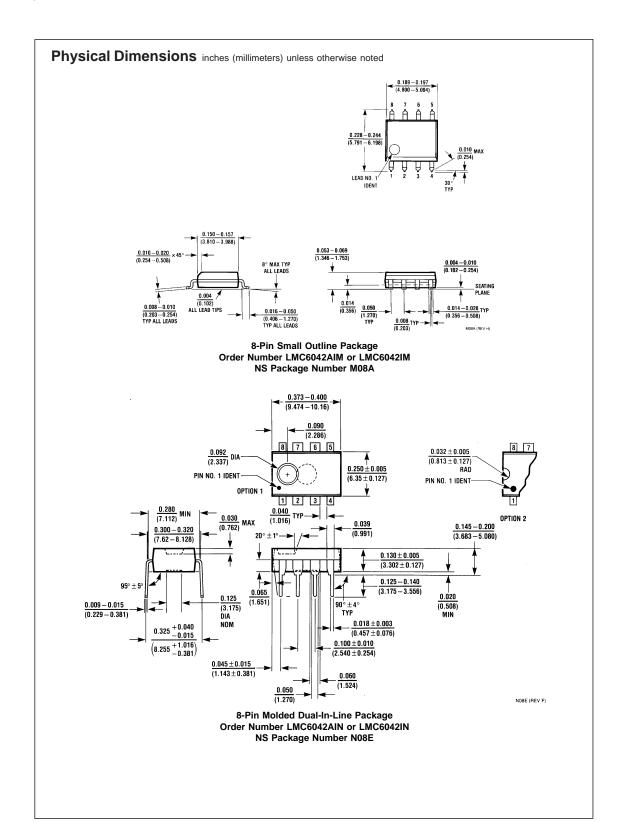


FIGURE 12. AC Coupled Power Amplifier



Notes

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- A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.



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