

LMC646x Dual and Quad, Micropower, Rail-to-Rail Input/Output, CMOS Operational Amplifiers

1 Features

- Typical values unless otherwise noted
- Ultra low supply current; 20 μ A/amplifier
- Specified characteristics at 3V and 5V
- Rail-to-rail input common-mode voltage range
- Rail-to-rail output swing
 - Within 10mV of rail, $V_S = 5V$ and $R_L = 25k\Omega$
- Low input current: 150fA
- Low input offset voltage: 0.25mV

2 Applications

- Battery-operated circuits
- Transducer interface circuits
- Portable-communication devices
- Medical applications
- Battery monitoring

3 Description

The LMC6462 and LMC6464 (LMC646x) are micropower versions of the popular LMC6482 and LMC6484, combining a rail-to-rail input and output range with very low power consumption.

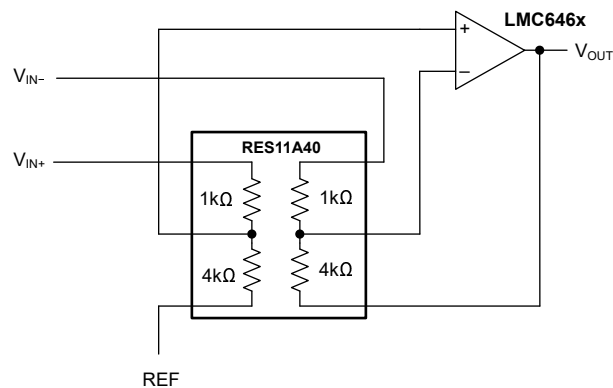
The LMC646x provide an input common-mode voltage range that exceeds both rails. The rail-to-rail output swing of the amplifiers, specified for loads down to 25k Ω , provides maximum dynamic signal range. This rail-to-rail performance of the amplifiers, combined with a high voltage gain, makes these device unique among rail-to-rail amplifiers. The LMC646x are an excellent upgrade for circuits using limited common-mode range amplifiers.

The LMC646x, with specifications at 3V and 5V, is an excellent choice for low-voltage applications. A quiescent power consumption of 60 μ W per amplifier (at $V_S = 3V$) can extend the useful life of battery-operated systems. The 150fA input current, low offset voltage of 0.25mV, and 85dB CMRR maintain accuracy in battery-powered systems.

Device Information

PART NUMBER	CHANNEL COUNT	PACKAGE ⁽¹⁾
LMC6462	Dual	D (SOIC, 8)
		P (PDIP, 8)
LMC6464	Quad	D (SOIC, 14)
		N (PDIP, 14)

(1) For more information, see [Section 10](#).



Difference Amplifier With RES11A



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4 Pin Configuration and Functions

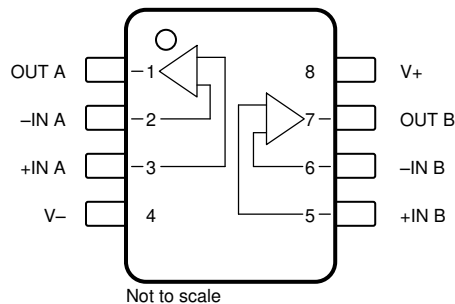


Figure 4-1. LMC6462: D Package, 8-Pin SOIC, and P Package, 8-Pin PDIP (Top View)

Table 4-1. Pin Functions: LMC6462

PIN		TYPE	DESCRIPTION
NAME	NO.		
-IN A	2	Input	Inverting input channel A
-IN B	6	Input	Inverting input channel B
+IN A	3	Input	Noninverting input channel A
+IN B	5	Input	Noninverting input channel B
OUT A	1	Output	Output channel A
OUT B	7	Output	Output channel B
V-	4	Power	Negative supply
V+	8	Power	Positive supply

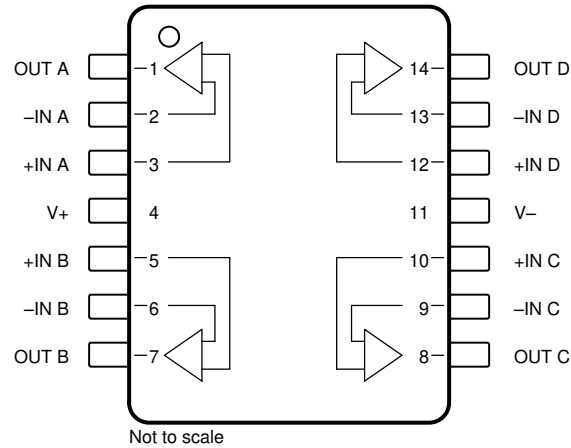


Figure 4-2. LMC6464: D Package, 14-Pin SOIC, and N Package, 14-Pin PDIP (Top View)

Table 4-2. Pin Functions: LMC6464

PIN		TYPE	DESCRIPTION
NAME	NO.		
-IN A	2	Input	Inverting input channel A
-IN B	6	Input	Inverting input channel B
-IN C	9	Input	Inverting input channel C
-IN D	13	Input	Inverting input channel D
+IN A	3	Input	Noninverting input channel A
+IN B	5	Input	Noninverting input channel B
+IN C	10	Input	Noninverting input channel C
+IN D	12	Input	Noninverting input channel D
OUT A	1	Output	Output channel A
OUT B	7	Output	Output channel B
OUT C	8	Output	Output channel C
OUT D	14	Output	Output channel D
V-	11	Power	Negative supply
V+	4	Power	Positive supply

5 Specifications

5.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)^{(1) (2)}

		MIN	MAX	UNIT
	Differential input voltage		±Supply voltage	V
V _S	Supply voltage, V _S = (V+) – (V–)		16	V
	Voltage at input/output pin	(V–) – 0.3	(V+) + 0.3	V
	Current at input pin ⁽³⁾		±5	mA
	Current at output pin ^{(4) (5)}		±30	mA
	Current at power supply pin		40	mA
T _J	Junction temperature ⁽⁶⁾		150	°C
T _{stg}	Storage temperature	–65	150	°C
	Lead temperature (soldering, 10s)		260	°C

- (1) Operation outside the *Absolute Maximum Ratings* may cause permanent device damage. *Absolute Maximum Ratings* do not imply functional operation of the device at these or any other conditions beyond those listed under *Recommended Operating Conditions*. If used outside the *Recommended Operating Conditions* but within the *Absolute Maximum Ratings*, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.
- (2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/Distributors for availability and specifications.
- (3) Limiting input pin current is only necessary for input voltages that exceed absolute maximum input voltage ratings.
- (4) Applies to both single supply and split-supply operation. Continuous short circuit operation at elevated ambient temperature can result in exceeding the maximum allowed junction temperature of 150°C. Output currents in excess of ±30mA over long term can adversely affect reliability.
- (5) Do not short circuit output to V+, when V+ is greater than 13V or reliability is adversely affected.
- (6) 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) / θ_{JA}. All numbers apply for packages soldered directly into a PCB.

5.2 ESD Ratings

			VALUE	UNIT
V _(ESD)	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾	±2000	V

- (1) JEDEC document JEP155 states that 500V HBM allows safe manufacturing with a standard ESD control process.

5.3 Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
V _S	Supply voltage, V _S = (V+) – (V–)	3		15.5	V
T _J	Junction temperature	–40		85	°C

5.4 Thermal Information for LMC6462

THERMAL METRIC ⁽¹⁾		LMC6462		UNIT
		D (SOIC)	P (PDIP)	
		8 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	193	115	°C/W
$R_{\theta JC(top)}$	Junction-to-case(top) thermal resistance	52.0	53.7	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	56.9	39.5	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	6.8	19.5	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	56.1	38.5	°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.

5.5 Thermal Information for LMC6464

THERMAL METRIC ⁽¹⁾		LMC6464		UNIT
		D (SOIC)	NFF (PDIP)	
		14 PINS	14 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	126	81	°C/W
$R_{\theta JC(top)}$	Junction-to-case(top) thermal resistance	34.6	31.9	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	34.3	26.0	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	4.7	9.9	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	33.7	25.4	°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.

5.6 Electrical Characteristics for $V_S = \pm 2.25V$ or $V_S = 5V$

at $T_A = T_J = 25^\circ C$, $V_+ = 5V$, $V_- = 0V$, $V_{CM} = V_{OUT} = V_+ / 2$, and $R_L > 1M\Omega$ connected to $V_+ / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT	
OFFSET VOLTAGE								
V_{OS}	Input offset voltage	LMC646xA			± 0.25	± 0.50	mV	
			$T_J = -40^\circ C$ to $+85^\circ C$					± 1.2
		LMC646xB			± 0.25	± 3		
			$T_J = -40^\circ C$ to $+85^\circ C$					
dV_{OS}/dT	Input offset voltage drift		$T_J = -40^\circ C$ to $+85^\circ C$		1		$\mu V/^\circ C$	
PSRR	Power-supply rejection ratio	Positive $5V \leq V_+ \leq 15V$	LMC646xA		70	85	dB	
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$		67			
			LMC646xB		65	85		
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$		62			
		Negative $V_+ = 0V, -15V \leq V_- \leq -5V$	LMC646xA		70	85		
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$		67			
			LMC646xB		65	85		
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$		62			
INPUT BIAS CURRENT								
I_B	Input bias current ⁽¹⁾				± 0.15		pA	
		$T_J = -40^\circ C$ to $+85^\circ C$				± 10		
I_{OS}	Input offset current ⁽¹⁾				± 0.075		pA	
		$T_J = -40^\circ C$ to $+85^\circ C$				± 5		
NOISE								
e_n	Input voltage noise density	$f = 1kHz, V_{CM} = 1V$			80		nV/\sqrt{Hz}	
i_n	Input current noise density	$f = 1kHz$			30		fA/\sqrt{Hz}	
INPUT VOLTAGE								
V_{CM}	Common-mode voltage	To positive rail $V_+ = 5V, CMRR \geq 50dB$		5.25	5.30	V		
			$T_J = -40^\circ C$ to $+85^\circ C$	5.00				
		To negative rail $V_+ = 5V, CMRR \geq 50dB$			-0.20		-0.10	
			$T_J = -40^\circ C$ to $+85^\circ C$				0.00	
		To positive rail $V_+ = 5V, CMRR \geq 50dB$		15.25	15.30			
			$T_J = -40^\circ C$ to $+85^\circ C$	15.00				
		To negative rail $V_+ = 5V, CMRR \geq 50dB$			-0.20		-0.15	
			$T_J = -40^\circ C$ to $+85^\circ C$				0.00	
CMRR	Common-mode rejection ratio	$V_+ = 15V$ $0V \leq V_{CM} \leq 15V$	LMC646xA	70	85	dB		
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$	67				
			LMC646xB	65	85			
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$	62				
		$V_+ = 5V$ $0V \leq V_{CM} \leq 5V$	LMC646xA	70	85			
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$	67				
			LMC646xB	65	85			
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$	62				

5.6 Electrical Characteristics for $V_S = \pm 2.25V$ or $V_S = 5V$ (continued)

at $T_A = T_J = 25^\circ C$, $V_+ = 5V$, $V_- = 0V$, $V_{CM} = V_{OUT} = V_+ / 2$, and $R_L > 1M\Omega$ connected to $V_+ / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT IMPEDANCE						
R_{IN}	Input resistance			> 10		$T\Omega$
C_{IN}	Common-mode input capacitance			3		pF
OPEN-LOOP GAIN						
A_{OL}	Open-loop voltage gain	Sourcing, $V_+ = 15V$, $7.5V < V_O < 11.5V$, $V_{CM} = 7.5V$,	$R_L = 100k\Omega$ to 7.5V	3000		V/mV
			$R_L = 25k\Omega$ to 7.5V	2500		
		Sinking, $V_+ = 15V$, $3.5V < V_O < 7.5V$, $V_{CM} = 7.5V$,	$R_L = 100k\Omega$ to 7.5V	400		
			$R_L = 25k\Omega$ to 7.5V	200		
FREQUENCY RESPONSE						
GBW	Gain bandwidth product			50		kHz
SR	Slew rate ⁽²⁾	$V_+ = 15V$, 10V step, $G = 1$		15	28	V/ms
				8		
G_m	Gain margin			15		dB
	Crosstalk	Dual and quad channel, $V_+ = 15V$, $R_L = 100k\Omega$ to 7.5V, $f = 1kHz$, $V_{OUT} = 12V_{PP}$		130		dB

5.6 Electrical Characteristics for $V_S = \pm 2.25V$ or $V_S = 5V$ (continued)

at $T_A = T_J = 25^\circ C$, $V_+ = 5V$, $V_- = 0V$, $V_{CM} = V_{OUT} = V_+ / 2$, and $R_L > 1M\Omega$ connected to $V_+ / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT	
OUTPUT								
V_O	Voltage output swing	Positive rail $V_+ = 5V$, $R_L = 100k\Omega$ to $V_+ / 2$	LMC646xA	4.990	4.995		V	
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$	4.980				
			LMC646xB	4.950	4.995			
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$	4.925				
		Negative rail $V_+ = 5V$, $R_L = 100k\Omega$ to $V_+ / 2$	LMC646xA		0.005	0.010		
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$			0.020		
			LMC646xB		0.005	0.050		
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$			0.075		
		Positive rail $V_+ = 5V$, $R_L = 25k\Omega$ to $V_+ / 2$	LMC646xA	4.975	4.990			
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$	4.965				
			LMC646xB	4.950	4.990			
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$	4.850				
		Negative rail $V_+ = 5V$, $R_L = 25k\Omega$ to $V_+ / 2$	LMC646xA		0.01	0.02		
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$			0.035		
			LMC646xB		0.01	0.050		
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$			0.150		
		Positive rail $V_+ = 15V$, $R_L = 100k\Omega$ to $V_+ / 2$	LMC646xA	14.975	14.990			
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$	14.965				
			LMC646xB	14.950	14.990			
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$	14.925				
		Negative rail $V_+ = 15V$, $R_L = 100k\Omega$ to $V_+ / 2$	LMC646xA		0.01	0.025		
			LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$			0.035		
			LMC646xB		0.01	0.050		
			LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$			0.075		
Positive rail $V_+ = 15V$, $R_L = 25k\Omega$ to $V_+ / 2$	LMC646xA	14.900	14.965					
	LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$	14.850						
	LMC646xB	14.850	14.965					
	LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$	14.800						
Negative rail $V_+ = 15V$, $R_L = 25k\Omega$ to $V_+ / 2$	LMC646xA		0.025	0.050				
	LMC646xA, $T_J = -40^\circ C$ to $+85^\circ C$			0.150				
	LMC646xB		0.025	0.100				
	LMC646xB, $T_J = -40^\circ C$ to $+85^\circ C$			0.200				

5.6 Electrical Characteristics for $V_S = \pm 2.25V$ or $V_S = 5V$ (continued)

at $T_A = T_J = 25^\circ C$, $V_+ = 5V$, $V_- = 0V$, $V_{CM} = V_{OUT} = V_+ / 2$, and $R_L > 1M\Omega$ connected to $V_+ / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
I_{SC}	Short-circuit current	Sourcing $V_{OUT} = 0V$		19	27		mA
			$T_J = -40^\circ C$ to $+85^\circ C$	15			
		Sinking $V_{OUT} = 5V$		22	27		
			$T_J = -40^\circ C$ to $+85^\circ C$	17			
		Sourcing $V_+ = 15V$, $V_{OUT} = 0V$	$T_J = -40^\circ C$ to $+85^\circ C$	24	38		
Sinking $V_+ = 15V$, $V_{OUT} = 12V^{(3)}$	$T_J = -40^\circ C$ to $+85^\circ C$	17					
POWER SUPPLY							
I_Q	Quiescent current	$V_{OUT} = V_+ / 2$	LMC6462		40	55	μA
			LMC6462, $T_J = -40^\circ C$ to $+85^\circ C$			70	
			LMC6464		80	110	
			LMC6464, $T_J = -40^\circ C$ to $+85^\circ C$			140	
		$V_+ = 15V$, $V_{OUT} = V_+ / 2$	LMC6462		50	60	
			LMC6462, $T_J = -40^\circ C$ to $+85^\circ C$			70	
			LMC6464		90	120	
			LMC6464, $T_J = -40^\circ C$ to $+85^\circ C$			140	

- (1) Specified limits are dictated by tester limitations and not device performance. Actual performance is reflected in the typical value.
- (2) Number specified is the slower of either the positive or negative slew rates.
- (3) Do not short circuit output to V_+ , when V_+ is greater than 13V or reliability is adversely affected.

5.7 Electrical Characteristics for $V_S = \pm 1.5V$ or $V_S = 3V$

at $T_A = 25^\circ C$, $V_+ = 3V$, $V_- = 0V$, $V_{CM} = V_{OUT} = V_+ / 2$, and $R_L > 1M\Omega$ connected to $V_+ / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OFFSET VOLTAGE						
V_{OS}	Input offset voltage	LMC646xA	$T_A = -40^\circ C$ to $+85^\circ C$	± 0.9	± 2	mV
				± 2.7		
		LMC646xB	$T_A = -40^\circ C$ to $+85^\circ C$	± 0.9	± 3	
				± 3.7		
dV_{OS}/dT	Input offset voltage drift	$T_A = -40^\circ C$ to $+85^\circ C$		2		$\mu V/^\circ C$
PSRR	Power-supply rejection ratio	$3V \leq V_+ \leq 15V$	60	80		dB
INPUT BIAS CURRENT						
I_B	Input bias current ⁽¹⁾	$T_A = -40^\circ C$ to $+85^\circ C$	± 0.15		± 10	pA
I_{OS}	Input offset current ⁽¹⁾	$T_A = -40^\circ C$ to $+85^\circ C$	± 0.075		± 5	pA
NOISE						
e_n	Input voltage noise density	$f = 1kHz$, $V_{CM} = 1V$		80		nV/\sqrt{Hz}
i_n	Input current noise density	$f = 1kHz$		30		fA/\sqrt{Hz}
INPUT VOLTAGE						
V_{CM}	Common-mode voltage range	To positive rail $V_+ = 5V$, $CMRR \geq 50dB$	3	3		V
		To negative rail $V_+ = 5V$, $CMRR \geq 50dB$		-0.1	0	
CMRR	Common-mode rejection ratio	$0V \leq V_{CM} \leq 3V$	60	74		dB
FREQUENCY RESPONSE						
GBW	Gain bandwidth product			50		kHz
SR	Slew rate ⁽²⁾	$G = 1, 2V$ step		23		V/ms
OUTPUT						
V_O	Voltage output swing	Positive rail $R_L = 25k\Omega$ to $V_+ / 2$	2.95	2.9		V
		Negative rail $R_L = 25k\Omega$ to $V_+ / 2$		0.1	0.15	V
POWER SUPPLY						
I_Q	Quiescent current	$V_{OUT} = V_+ / 2$	LMC6462	40	55	μA
			LMC6462, $T_A = -40^\circ C$ to $+85^\circ C$		70	
			LMC6464	80	110	
			LMC6464, $T_A = -40^\circ C$ to $+85^\circ C$		140	

(1) Specified limits are dictated by tester limitations and not device performance. Actual performance is reflected in the typical value.

(2) Number specified is the slower of either the positive or negative slew rates.

6 Typical Characteristics

at $V_S = 5V$, single supply, and $T_A = 25^\circ C$ (unless otherwise specified)

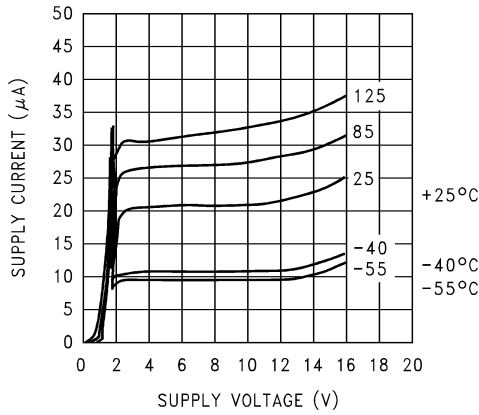


Figure 6-1. Supply Current vs Supply Voltage

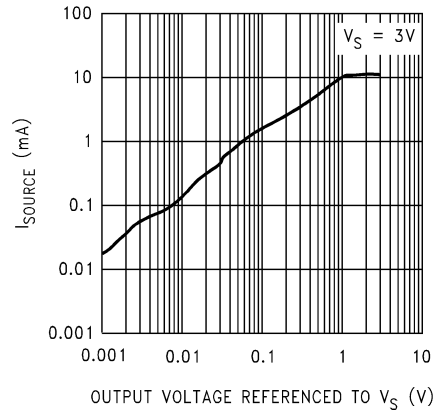


Figure 6-2. Sourcing Current vs Output Voltage

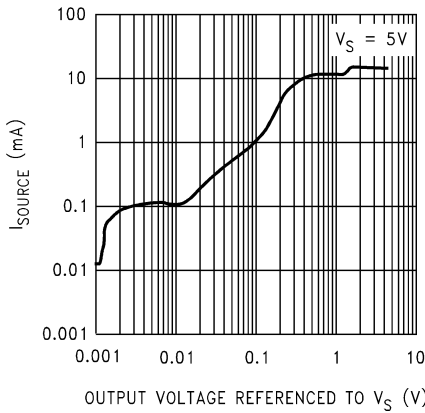


Figure 6-3. Sourcing Current vs Output Voltage

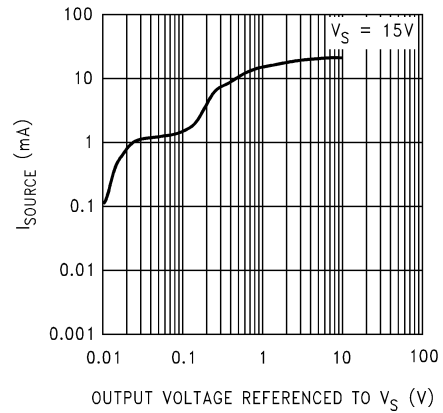


Figure 6-4. Sourcing Current vs Output Voltage

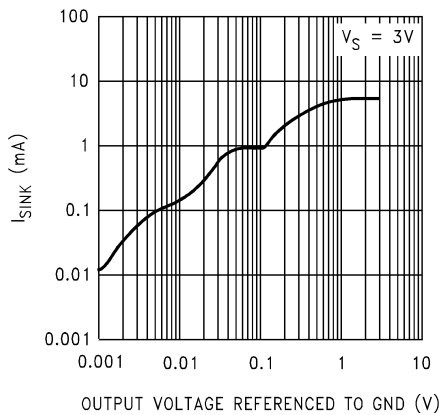


Figure 6-5. Sinking Current vs Output Voltage

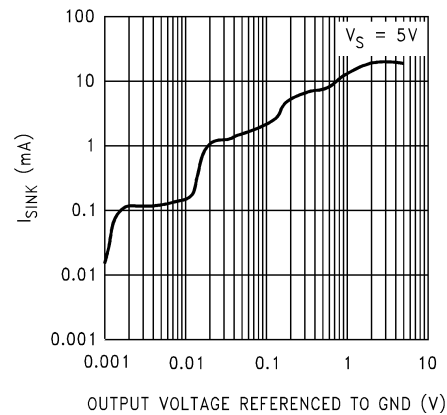


Figure 6-6. Sinking Current vs Output Voltage

6 Typical Characteristics (continued)

at $V_S = 5V$, single supply, and $T_A = 25^\circ C$ (unless otherwise specified)

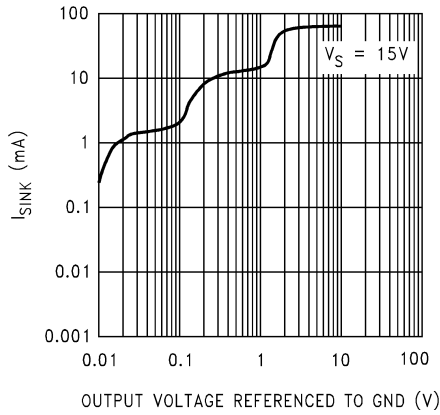


Figure 6-7. Sinking Current vs Output Voltage

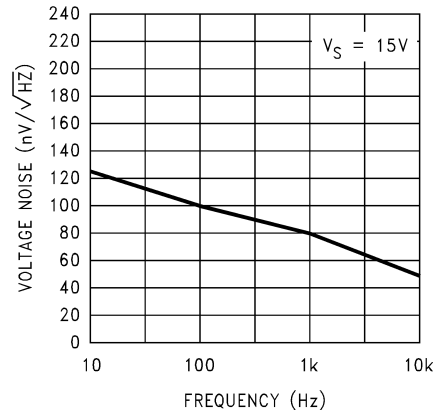


Figure 6-8. Input Voltage Noise vs Frequency

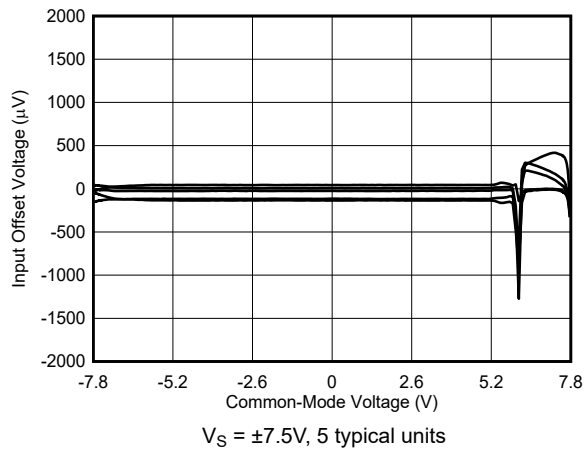


Figure 6-9. Input Offset Voltage vs Common-Mode Voltage

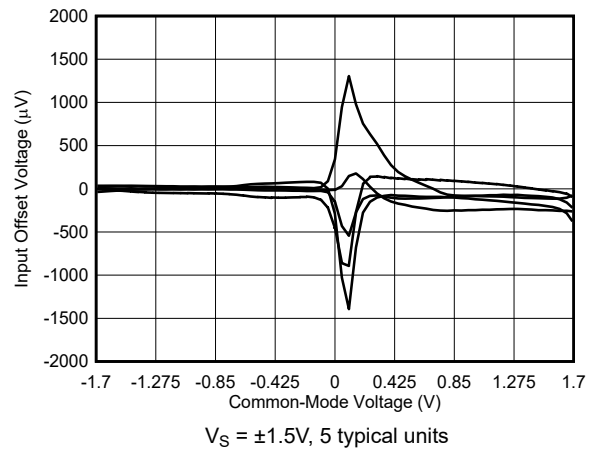


Figure 6-10. Input Offset Voltage vs Common-Mode Voltage

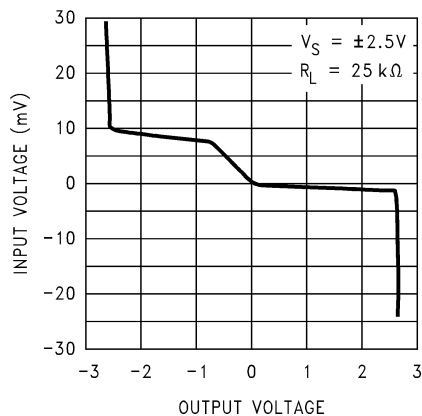


Figure 6-11. Input Voltage vs Output Voltage

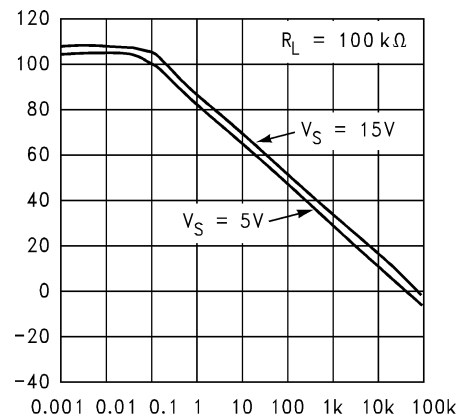


Figure 6-12. Open-Loop Frequency Response

6 Typical Characteristics (continued)

at $V_S = 5V$, single supply, and $T_A = 25^\circ C$ (unless otherwise specified)

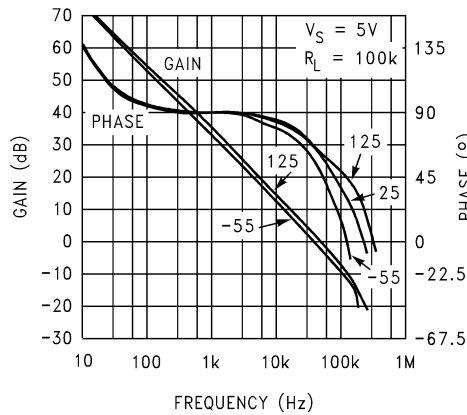


Figure 6-13. Open-Loop Frequency Response vs Temperature

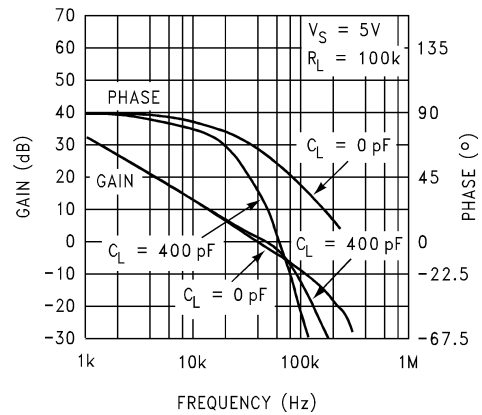


Figure 6-14. Gain and Phase vs Capacitive Load

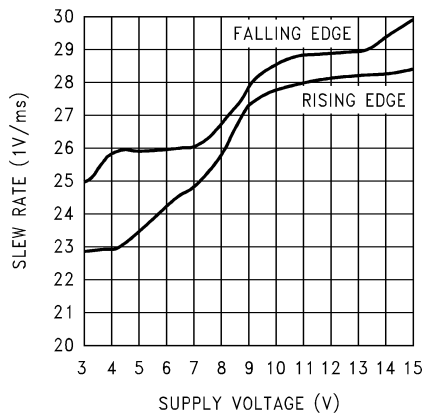


Figure 6-15. Slew Rate vs Supply Voltage

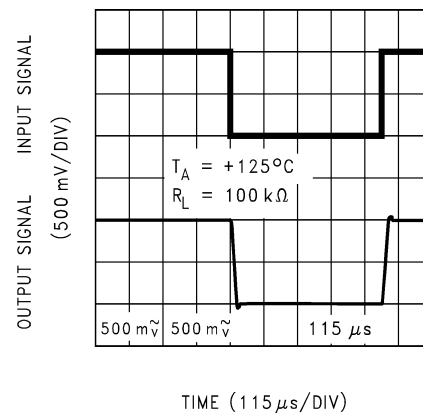


Figure 6-16. Noninverting Large-Signal Pulse Response

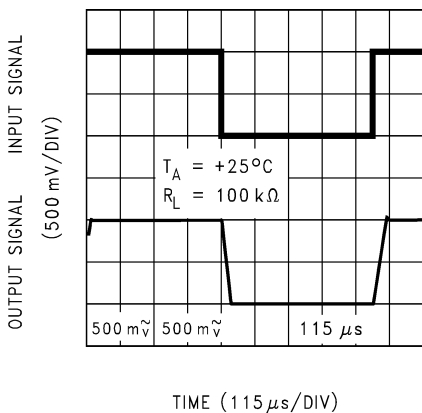


Figure 6-17. Noninverting Large-Signal Pulse Response

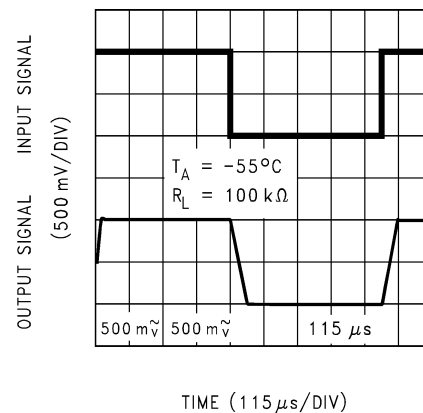


Figure 6-18. Noninverting Large-Signal Pulse Response

6 Typical Characteristics (continued)

at $V_S = 5V$, single supply, and $T_A = 25^\circ C$ (unless otherwise specified)

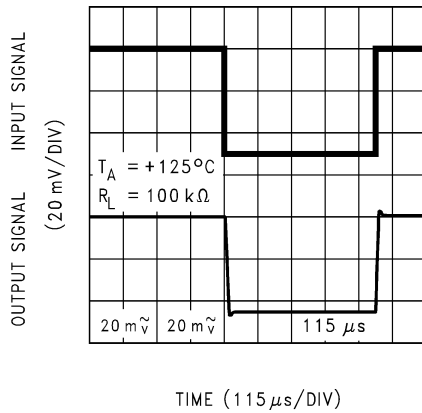


Figure 6-19. Noninverting Small-Signal Pulse Response

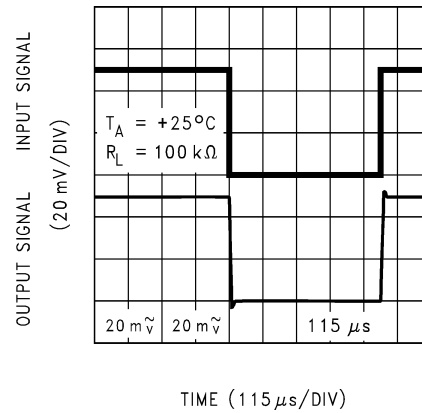


Figure 6-20. Noninverting Small-Signal Pulse Response

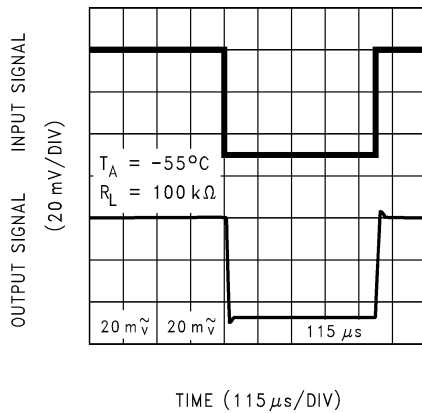


Figure 6-21. Noninverting Small-Signal Pulse Response

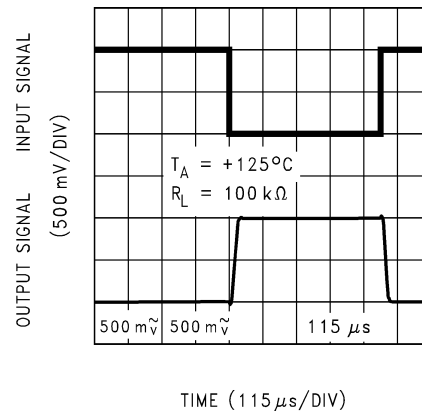


Figure 6-22. Inverting Large-Signal Pulse Response

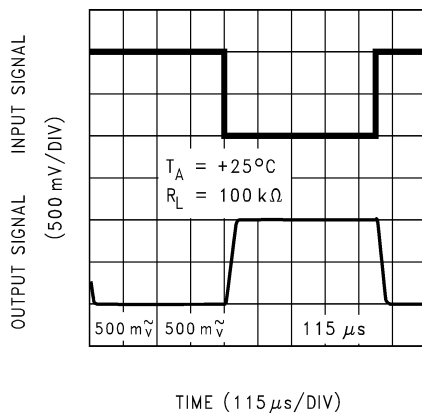


Figure 6-23. Inverting Large-Signal Pulse Response

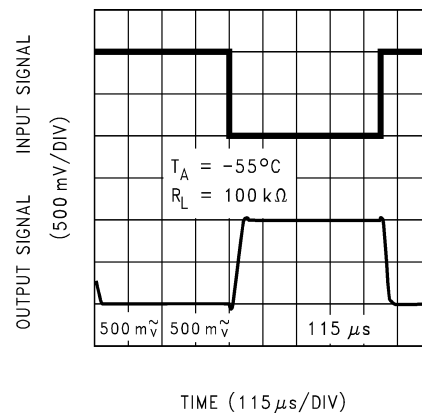


Figure 6-24. Inverting Large-Signal Pulse Response

6 Typical Characteristics (continued)

at $V_S = 5V$, single supply, and $T_A = 25^\circ C$ (unless otherwise specified)

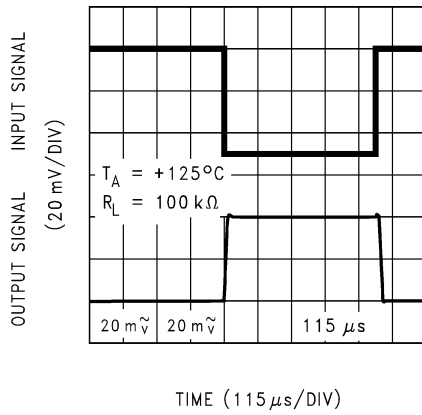


Figure 6-25. Inverting Small-Signal Pulse Response

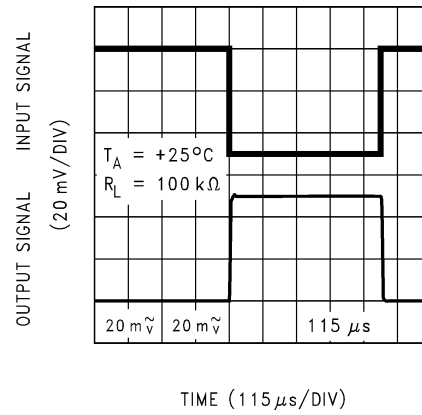


Figure 6-26. Inverting Small-Signal Pulse Response

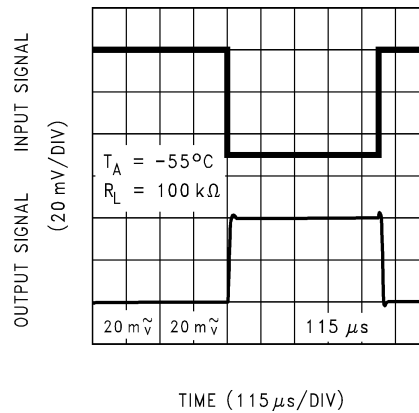


Figure 6-27. Inverting Small-Signal Pulse Response

7 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, as well as validating and testing their design implementation to confirm system functionality.

7.1 Application Information

7.1.1 Input Common-Mode Voltage Range

The LMC646x have a rail-to-rail input common-mode voltage range. Some dc parameters such as input offset voltage, common-mode rejection, and power supply rejection can be degraded for common-mode voltages (V_{CM}) near the positive supply rail. The LMC646x is designed to achieve the best dc precision when the common-mode is limited to $V_{CM} < (V+) - 2V$. Figure 7-1 shows an input voltage exceeding both supplies with no resulting phase inversion on the output.

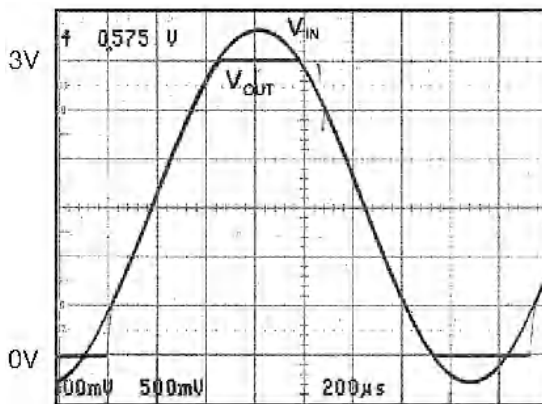


Figure 7-1. An Input Voltage Signal Exceeds the LMC646x Power Supply Voltage with No Output Phase Inversion

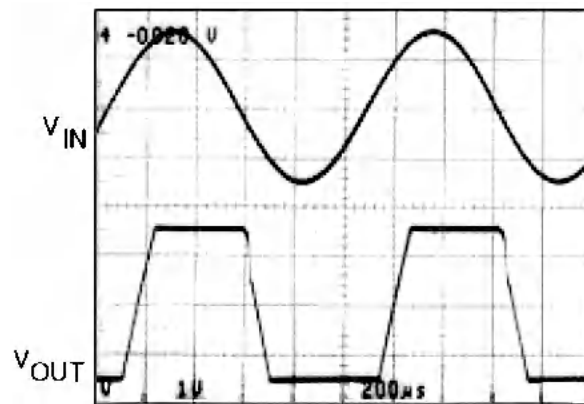


Figure 7-2. A $\pm 7.5V$ Input Signal Greatly Exceeds the 3V Supply in Figure 7-3 Causing No Phase Inversion Due to R_I

The absolute maximum input voltage at $V+ = 3V$ is 300mV beyond either supply rail at room temperature. Voltages greatly exceeding this absolute maximum rating, as in Figure 7-2, can cause excessive current to flow in or out of the input pins, possibly affecting reliability. The input current can be externally limited to $\pm 5mA$, with an input resistor, as shown in Figure 7-3.

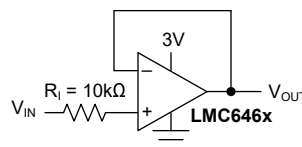


Figure 7-3. Input Current Protection for Voltages Exceeding the Supply Voltage

7.1.2 Rail-to-Rail Output

The approximated output resistance of the LMC646x is 180Ω sourcing, and 130Ω sinking at $V_S = 3V$, and 110Ω sourcing and 83Ω sinking at $V_S = 5V$. The maximum output swing can be estimated as a function of load using the calculated output resistance.

7.1.3 Capacitive Load Tolerance

The LMC646x can typically drive a $200pF$ load with $V_S = 5V$ at unity gain without oscillating. The unity gain follower is the most sensitive configuration to capacitive load. Direct capacitive loading reduces the phase margin of op amps. The combination of the op amp output impedance and the capacitive load induces phase lag. This results in either an underdamped pulse response or oscillation.

Capacitive load compensation can be accomplished using resistive isolation as shown in [Figure 7-4](#). If there is a resistive component of the load in parallel to the capacitive component, the isolation resistor and the resistive load create a voltage divider at the output. This introduces a DC error at the output.

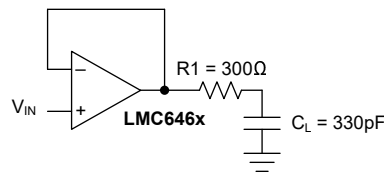


Figure 7-4. Resistive Isolation of a 300pF Capacitive Load

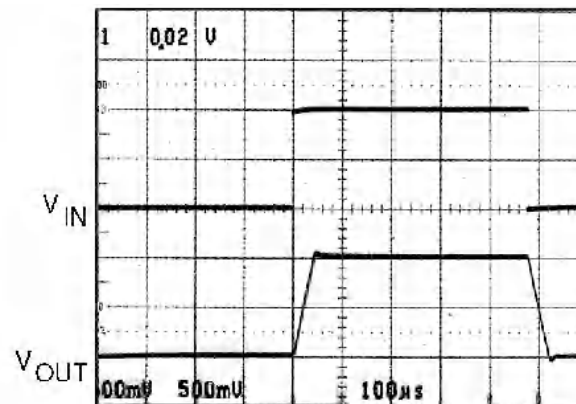


Figure 7-5. Pulse Response of the LMC6462 Circuit Shown in [Figure 7-4](#)

[Figure 7-5](#) displays the pulse response of the LMC646x circuit in [Figure 7-4](#).

Another circuit, shown in [Figure 7-6](#), is also used to indirectly drive capacitive loads. This circuit is an improvement to the circuit shown in [Figure 7-4](#) because [Figure 7-6](#) provides dc accuracy as well as ac stability. $R1$ and $C1$ serve to counteract the loss of phase margin by feeding the high frequency component of the output signal back to the amplifiers inverting input, thereby preserving phase margin in the overall feedback loop. The values of $R1$ and $C1$ can be experimentally determined by the system designer for the desired pulse response. Increased capacitive drive is possible by increasing the value of the capacitor in the feedback loop.

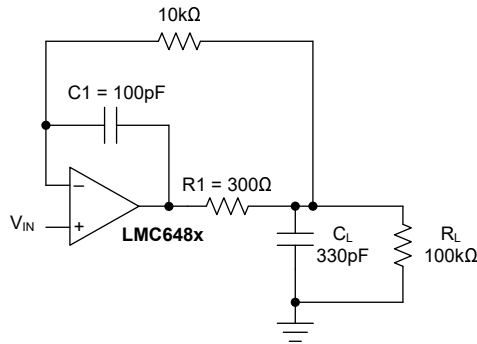


Figure 7-6. Noninverting Amplifier, Compensated to Handle a 300pF Capacitive and 100kΩ Resistive Load

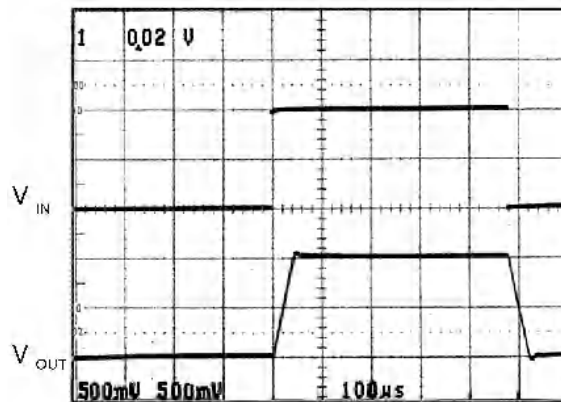


Figure 7-7. Pulse Response of LMC6462 Circuit in Figure 7-6

The pulse response of the circuit shown in [Figure 7-6](#) is shown in [Figure 7-7](#)

7.1.4 Compensating for Input Capacitance

The use of large values of feedback resistance is quite common to do with amplifiers that have ultra-low input current, like the LMC646x. Large feedback resistors can react with small values of input capacitance due to transducers, photodiodes, and circuits board parasitics to reduce phase margins.

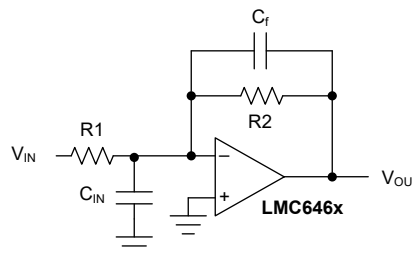


Figure 7-8. Canceling the Effect of Input Capacitance

The effect of input capacitance can be compensated for by adding a feedback capacitor. The feedback capacitor (as in [Figure 7-8](#)), C_F , is first estimated by:

$$\frac{1}{2\pi R1C_{IN}} \geq \frac{1}{2\pi R2C_F} \quad (1)$$

or

$$R1C_{IN} \leq R2C_F \quad (2)$$

which typically provides significant overcompensation.

Printed circuit board stray capacitance can be larger or smaller than that of a breadboard, so the actual optimum value for C_F can be different. Check the values of C_F on the actual circuit. (Refer to the LMC660 quad CMOS amplifier data sheet for a more detailed discussion.)

7.1.5 Offset Voltage Adjustment

Offset voltage adjustment circuits are illustrated in [Figure 7-9](#) and [Figure 7-10](#). Large-value resistances and potentiometers are used to reduce power consumption while providing typically $\pm 2.5\text{mV}$ of adjustment range, referred to the input, for both configurations with $V_S = \pm 5\text{V}$.

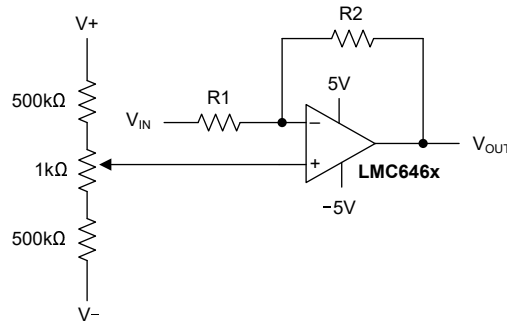


Figure 7-9. Inverting Configuration Offset Voltage Adjustment

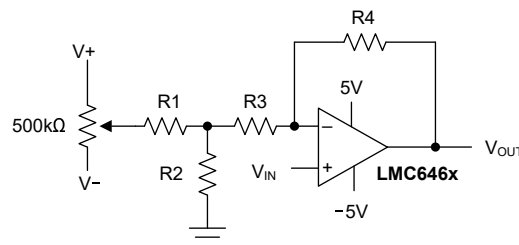


Figure 7-10. Noninverting Configuration Offset Voltage Adjustment

7.1.6 Instrumentation Circuits

The LMC646x has the high input impedance, large common-mode range and high CMRR needed for designing instrumentation circuits. Instrumentation circuits designed with the LMC646x can reject a larger range of common-mode signals than most in-amps. This makes instrumentation circuits designed with the LMC646x an excellent choice for noisy or industrial environments. Other applications that benefit from these features include analytic medical instruments, magnetic field detectors, gas detectors, and silicon-based transducers.

A small valued potentiometer is used in series with R_G to set the differential gain of the three op-amp instrumentation circuit in Figure 7-11. This combination is used instead of one large valued potentiometer to increase gain trim accuracy and reduce error due to vibration.

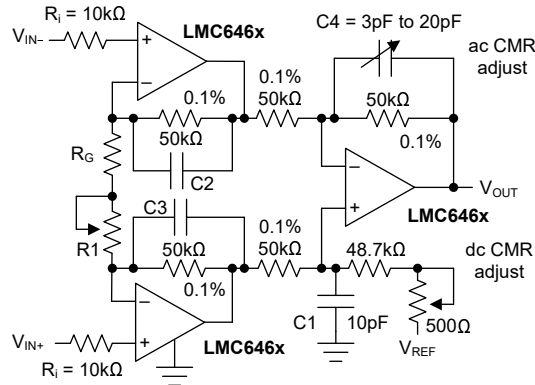


Figure 7-11. Low-Power Three Op-Amp Instrumentation Amplifier

A two op-amp instrumentation amplifier designed for a gain of 100 is shown in Figure 7-12. Low sensitivity trimming is made for offset voltage, CMRR and gain. Low cost and low power consumption are the main advantages of this two op-amp circuit.

Higher frequency and larger common-mode range applications are best facilitated by a three op-amp instrumentation amplifier.

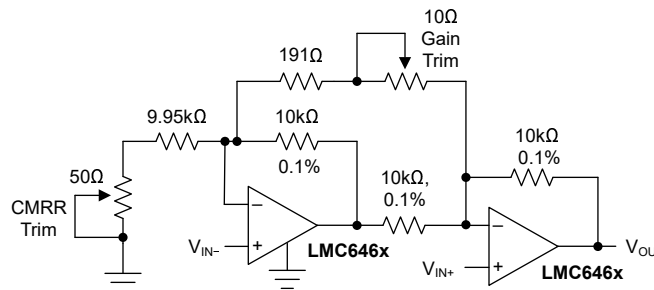


Figure 7-12. Low-Power Two Op Amp Instrumentation Amplifier

7.2 Typical Applications

7.2.1 Transducer Interface Circuits

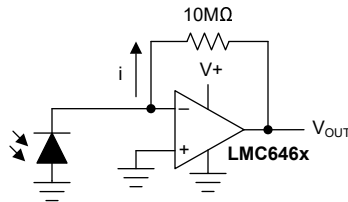


Figure 7-13. Photo Detector Circuit

Photocells can be used in portable light measuring instruments. The LMC646x, which can be operated off a battery, is an excellent choice for this circuit because of the very low input current and offset voltage performance.

7.2.2 LMC646x as a Comparator

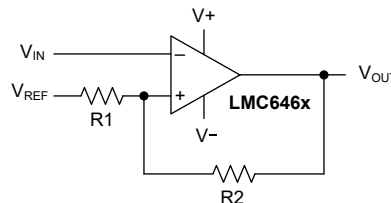


Figure 7-14. Comparator with Hysteresis

Figure 7-14 shows the application of the LMC646x as a comparator. The hysteresis is determined by the ratio of the two resistors. The LMC646x can thus be used as a micropower comparator, in applications where the quiescent current is an important parameter.

7.2.3 Half-Wave and Full-Wave Rectifiers

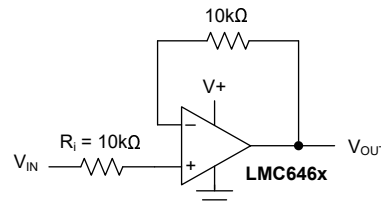


Figure 7-15. Half-Wave Rectifier with Input Current Protection (R_i)

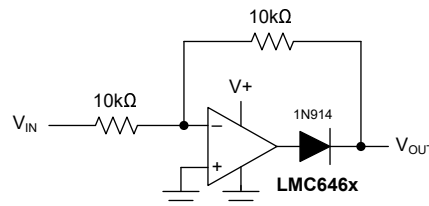


Figure 7-16. Full-Wave Rectifier with Input Current Protection (R_i)

In Figure 7-15 Figure 7-16, R_i limits current into the amplifier since excess current can be caused by the input voltage exceeding the supply voltage.

7.2.4 Precision Current Source

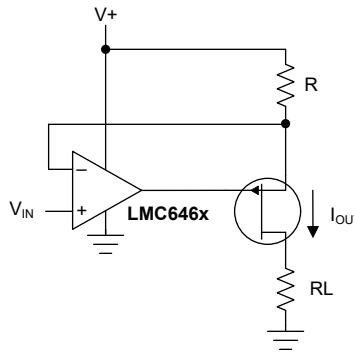


Figure 7-17. Precision Current Source

The output current I_{OUT} is given by:

$$I_{OUT} = \frac{(V+) - (V_{IN})}{R} \tag{3}$$

7.2.5 Oscillators

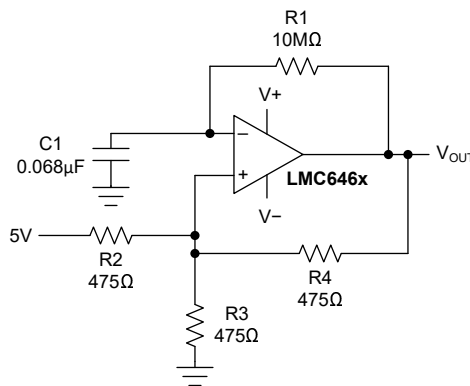


Figure 7-18. 1Hz Square-Wave Oscillator

For single supply 5V operation, the output of the circuit swings from 0V to 5V. The voltage divider set up by R_2 , R_3 and R_4 cause the noninverting input of the LMC646x to move from 1.67V (1/3 of 5V) to 3.33V (2/3 of 5V). This voltage behaves as the threshold voltage.

R_1 and C_1 determine the time constant of the circuit. The frequency of oscillation, f_{OSC} , is:

$$\frac{1}{2\Delta t} \tag{4}$$

where

- Δt = time the amplifier input takes to move from 1.67V to 3.33V.

The calculations are as follows:

$$1.67 = 5 \left(1 - e^{-\frac{t_1}{\tau}} \right) \tag{5}$$

where

- $\tau = RC = 0.68$ seconds
- $t_1 = 0.27$ seconds.

and

$$3.33 = 5 \left(1 - e^{-\frac{t_2}{\tau}} \right) \tag{6}$$

where

- $t_2 = 0.75$ seconds

Then,

$$f_{OSC} = \frac{1}{2\Delta t} = \frac{1}{2(0.75 - 0.27)} \cong 1\text{Hz} \tag{7}$$

7.2.6 Low Frequency Null

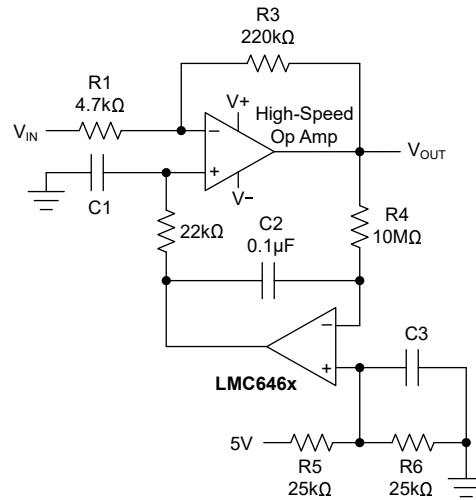


Figure 7-19. High Gain Amplifier with Low Frequency Null

Output offset voltage, V_{OS_OUT} , is the error introduced in the output voltage due to the inherent input offset voltage V_{OS} , of an amplifier.

$$V_{OS_OUT} = V_{OS} \times \text{Gain}$$

In the above configuration, the resistors R_5 and R_6 determine the nominal voltage around which the input signal, V_{IN} , is symmetrical. The high frequency component of V_{IN} is unaffected while the low frequency component is nulled since the dc level of the output is the input offset voltage of the LMC646x plus the bias voltage. This implies that the output offset voltage due to the top amplifier is eliminated.

7.3 Layout

7.3.1 Layout Guidelines

7.3.1.1 PCB Layout for High-Impedance Work

As a general rule, any circuit that must operate with less than 1000pA of leakage current requires special layout of the printed circuit board (PCB). When one wishes to take advantage of the ultra-low input current of the LMC646x, typically 150fA, an excellent layout is essential. Fortunately, the techniques of obtaining low leakages are quite simple. First, do not ignore the surface leakage of the PCB, even though the leakage current can sometimes appear acceptably low, because under conditions of high humidity or dust or contamination, the surface leakage can be appreciable.

To minimize the effect of any surface leakage, lay out a ring of foil completely surrounding the LMC646x inputs and the terminals of capacitors, diodes, conductors, resistors, relay terminals, and so forth connected to the inputs of the op amp, as in [Figure 7-20](#). To have a significant effect, place guard rings on both the top and bottom of the PCB. This PC foil must then be connected to a voltage that is at the same voltage as the amplifier inputs, because no leakage current can flow between two points at the same potential. For example, a PCB trace-to-pad resistance of 10^{12} , which is normally considered a very large resistance, can leak 5pA if the trace were a 5V bus adjacent to the pad of the input. This leakage can cause a 250 times degradation from the actual performance of the LMC646x. However, if a guard ring is held within 5mV of the inputs, then even a resistance of $10^{11}\Omega$ causes only 0.05pA of leakage current. See [Figure 7-21](#) through [Figure 7-23](#) for typical connections of guard rings for standard op-amp configurations

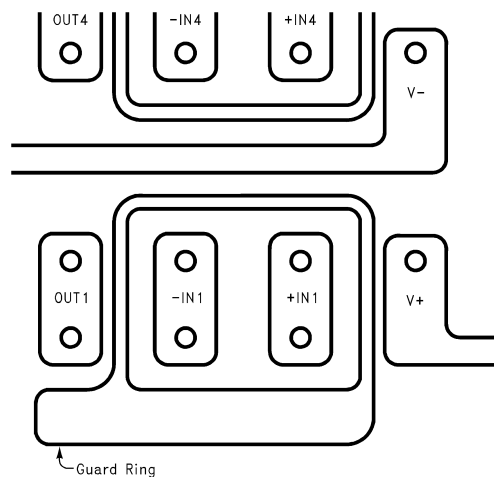


Figure 7-20. Example of Guard Ring in P.C. Board Layout

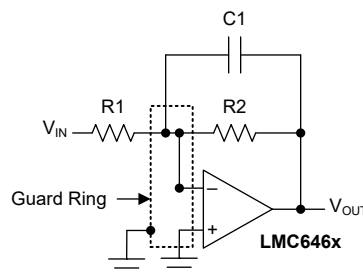


Figure 7-21. Typical Connections of Guard Rings – Inverting Amplifier

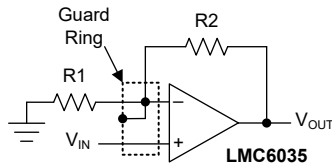


Figure 7-22. Typical Connections of Guard Rings – Non-Inverting Amplifier

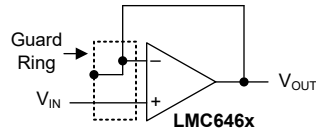
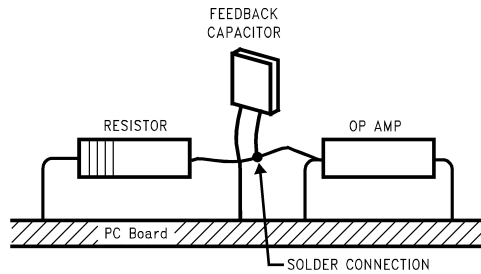


Figure 7-23. Typical Connections of Guard Rings – Follower

Be aware that when laying out a PCB for the sake of just a few circuits is not practical, another technique is even better than a guard ring on a PCB: Do not insert the input pin of the amplifier into the PCB at all, but bend the pin up in the air, and use only air as an insulator. Air is an excellent insulator. In this case you forgo some of the advantages of PCB construction, but the advantages are sometimes well worth the effort of using point-to-point up-in-the-air wiring. See [Figure 7-24](#).



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

Figure 7-24. Air Wiring

8 Device and Documentation Support

TI offers an extensive line of development tools. Tools and software to evaluate the performance of the device, generate code, and develop solutions are listed below.

8.1 Device Support

8.1.1 Development Support

8.1.1.1 PSpice® for TI

PSpice® for TI is a design and simulation environment that helps evaluate performance of analog circuits. Create subsystem designs and prototype solutions before committing to layout and fabrication, reducing development cost and time to market.

8.2 Documentation Support

8.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Notifications* 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.

8.4 Support Resources

TI E2E™ [support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is 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](#).

8.5 Trademarks

TI E2E™ is a trademark of Texas Instruments.

PSpice® is a registered trademark of Cadence Design Systems, Inc.

All trademarks are the property of their respective owners.

8.6 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.

8.7 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

9 Revision History

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

Changes from Revision D (March 2013) to Revision E (March 2025)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document.....	1
• Updated first page figure.....	1
• Added <i>Pin Configuration and Functions</i>	2
• Deleted note 2 from <i>Absolute Maximum Ratings</i>	4
• Added <i>ESD Ratings</i>	4
• Added <i>Thermal Information</i>	5
• Updated parameter names and symbols in both <i>Electrical Characteristics</i>	6
• Deleted notes 1, 2, and 3 from previous DC <i>Electrical Characteristics</i>	6
• Deleted notes 1 and 2 from previous AC <i>Electrical Characteristics</i>	6

• Moved note 4 conditions from previous DC <i>Electrical Characteristics</i> to open-loop gain test conditions.....	6
• Updated note 3 in previous AC <i>Electrical Characteristics</i> and moved conditions to slew rate test conditions...	6
• Deleted phase margin from <i>Electrical Characteristics</i>	6
• Moved note 3 conditions from previous AC <i>Electrical Characteristics</i> to crosstalk test conditions.....	6
• Changed short-circuit current ($V_+ = 15V$, sinking) TYP from 75mA to 38mA and MIN from 55mA to 28mA.....	6
• Changed short-circuit current ($V_+ = 15V$, sinking, $T_J = -40^\circ C$ to $+85^\circ C$) MIN from 45mA to 22mA.....	6
• Added Figure 6-9 and Figure 6-10.....	11
• Deleted Figures 12 to 15.....	11
• Updated description in <i>Input Common-Mode Voltage Range</i>	16

Changes from Revision C (March 2013) to Revision D (March 2013)	Page
• Changed layout of National Data Sheet to TI format.....	23

10 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 finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LMC6462AIM/NOPB	OBSOLETE	SOIC	D	8		TBD	Call TI	Call TI	-40 to 85	LMC64 62AIM	
LMC6462AIMX/NOPB	ACTIVE	SOIC	D	8	2500	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	LMC64 62AIM	Samples
LMC6462AIN/NOPB	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI	-40 to 85	LMC6462 AIN	
LMC6462BIM/NOPB	OBSOLETE	SOIC	D	8		TBD	Call TI	Call TI	-40 to 85	LMC64 62BIM	
LMC6462BIMX/NOPB	ACTIVE	SOIC	D	8	2500	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	LMC64 62BIM	Samples
LMC6462BIN/NOPB	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI	-40 to 85	LMC6462 BIN	
LMC6464AIM/NOPB	OBSOLETE	SOIC	D	14		TBD	Call TI	Call TI	-40 to 85	LMC6464 AIM	
LMC6464AIMX/NOPB	ACTIVE	SOIC	D	14	2500	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	LMC6464 AIM	Samples
LMC6464BIM/NOPB	OBSOLETE	SOIC	D	14		TBD	Call TI	Call TI	-40 to 85	LMC6464 BIM	
LMC6464BIMX/NOPB	ACTIVE	SOIC	D	14	2500	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	LMC6464 BIM	Samples
LMC6464BIN/NOPB	OBSOLETE	PDIP	N	14		TBD	Call TI	Call TI	-40 to 85	LMC6464BIN	

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

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TAPE AND REEL INFORMATION

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
LMC6462AIMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LMC6462BIMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LMC6464AIMX/NOPB	SOIC	D	14	2500	330.0	16.4	6.5	9.35	2.3	8.0	16.0	Q1
LMC6464BIMX/NOPB	SOIC	D	14	2500	330.0	16.4	6.5	9.35	2.3	8.0	16.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LMC6462AIMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LMC6462BIMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LMC6464AIMX/NOPB	SOIC	D	14	2500	356.0	356.0	35.0
LMC6464BIMX/NOPB	SOIC	D	14	2500	367.0	367.0	35.0

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.

N (R-PDIP-T**)

PLASTIC DUAL-IN-LINE PACKAGE

16 PINS SHOWN



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - Falls within JEDEC MS-001, except 18 and 20 pin minimum body length (Dim A).
 - The 20 pin end lead shoulder width is a vendor option, either half or full width.



D0014A

PACKAGE OUTLINE

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



4220718/A 09/2016

NOTES:

1. All linear dimensions are in millimeters. Dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm, per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.43 mm, per side.
5. Reference JEDEC registration MS-012, variation AB.

EXAMPLE BOARD LAYOUT

D0014A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE
SCALE:8X



SOLDER MASK DETAILS

4220718/A 09/2016

NOTES: (continued)

- 6. Publication IPC-7351 may have alternate designs.
- 7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

D0014A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:8X

4220718/A 09/2016

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.



D0008A

PACKAGE OUTLINE

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed $.006$ [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.

EXAMPLE BOARD LAYOUT

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE
 EXPOSED METAL SHOWN
 SCALE:8X



SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

- 6. Publication IPC-7351 may have alternate designs.
- 7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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