



# THE DATASHEET OF TLC27M2IPWR

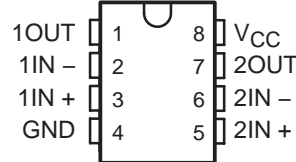


# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

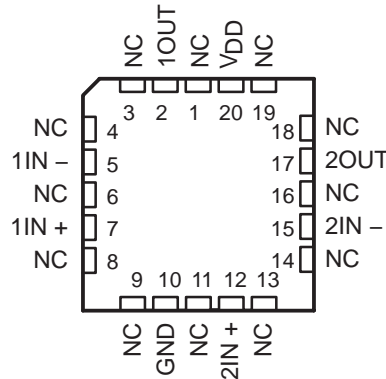
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- **Trimmed Offset Voltage:**  
TLC27M7 . . . 500  $\mu\text{V}$  Max at 25°C,  
 $V_{\text{DD}} = 5\text{ V}$
- **Input Offset Voltage Drift . . . Typically**  
0.1  $\mu\text{V}/\text{Month}$ , Including the First 30 Days
- **Wide Range of Supply Voltages Over Specified Temperature Ranges:**  
0°C to 70°C . . . 3 V to 16 V  
–40°C to 85°C . . . 4 V to 16 V  
–55°C to 125°C . . . 4 V to 16 V
- **Single-Supply Operation**
- **Common-Mode Input Voltage Range Extends Below the Negative Rail (C-Suffix, I-Suffix Types)**
- **Low Noise . . . Typically 32 nV/ $\sqrt{\text{Hz}}$  at  $f = 1\text{ kHz}$**
- **Low Power . . . Typically 2.1 mW at 25°C,  $V_{\text{DD}} = 5\text{ V}$**
- **Output Voltage Range Includes Negative Rail**
- **High Input impedance . . .  $10^{12}\ \Omega$  Typ**
- **ESD-Protection Circuitry**
- **Small-Outline Package Option Also Available in Tape and Reel**
- **Designed-In Latch-Up Immunity**

D, JG, P OR PW PACKAGE  
(TOP VIEW)

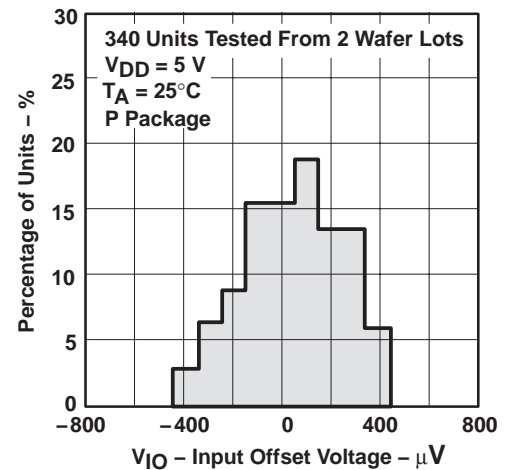


FK PACKAGE  
(TOP VIEW)



NC – No internal connection

DISTRIBUTION OF TLC27M7  
INPUT OFFSET VOLTAGE



## AVAILABLE OPTIONS

$T_{\text{A}}$	$V_{\text{IOmax}}$ AT 25°C	PACKAGE				
		SMALL OUTLINE (D)	CHIP CARRIER (FK)	CERAMIC DIP (JG)	PLASTIC DIP (P)	TSSOP (PW)
0°C to 70°C	500 $\mu\text{V}$	TLC27M7CD	—	—	TLC27M7CP	—
	2 mV	TLC27M2BCD	—	—	TLC27M2BCP	—
	5 mV	TLC27M2ACD	—	—	TLC27M2ACP	—
	10 mV	TLC27M2CD	—	—	TLC27M2CP	TLC27M2CPW
–40°C to 85°C	500 $\mu\text{V}$	TLC27M7ID	—	—	TLC27M7IP	—
	2 mV	TLC27M2BID	—	—	TLC27M2BIP	—
	5 mV	TLC27M2AID	—	—	TLC27M2AIP	—
	10 mV	TLC27M2ID	—	—	TLC27M2IP	TLC27M2IPW
–55°C to 125°C	500 $\mu\text{V}$	TLC27M7MD	TLC27M7MFK	TLC27M7MJG	TLC27M7MP	—
	10 mV	TLC27M2MD	TLC27M2MFK	TLC27M2MJG	TLC27M2MP	—

The D and PW package are available taped and reeled. Add R suffix to the device type (e.g., TLC27M7CDR). For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at [www.ti.com](http://www.ti.com).

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# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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## description

The TLC27M2 and TLC27M7 dual operational amplifiers combine a wide range of input offset voltage grades with low offset voltage drift, high input impedance, low noise, and speeds approaching that of general-purpose bipolar devices. These devices use Texas Instruments silicon-gate LinCMOS technology, which provides offset voltage stability far exceeding the stability available with conventional metal-gate processes.

The extremely high input impedance, low bias currents, and high slew rates make these cost-effective devices ideal for applications which have previously been reserved for general-purpose bipolar products, but with only a fraction of the power consumption. Four offset voltage grades are available (C-suffix and I-suffix types), ranging from the low-cost TLC27M2 (10 mV) to the high-precision TLC27M7 (500  $\mu$ V). These advantages, in combination with good common-mode rejection and supply voltage rejection, make these devices a good choice for new state-of-the-art designs as well as for upgrading existing designs.

In general, many features associated with bipolar technology are available on LinCMOS operational amplifiers, without the power penalties of bipolar technology. General applications such as transducer interfacing, analog calculations, amplifier blocks, active filters, and signal buffering are easily designed with the TLC27M2 and TLC27M7. The devices also exhibit low voltage single-supply operation, making them ideally suited for remote and inaccessible battery-powered applications. The common-mode input voltage range includes the negative rail.

A wide range of packaging options is available, including small-outline and chip-carrier versions for high-density system applications.

The device inputs and outputs are designed to withstand  $-100$ -mA surge currents without sustaining latch-up.

The TLC27M2 and TLC27M7 incorporate internal ESD-protection circuits that prevent functional failures at voltages up to 2000 V as tested under MIL-STD-883C, Method 3015.2; however, care should be exercised in handling these devices as exposure to ESD may result in the degradation of the device parametric performance.

The C-suffix devices are characterized for operation from 0°C to 70°C. The I-suffix devices are characterized for operation from  $-40$ °C to 85°C. The M-suffix devices are characterized for operation over the full military temperature range of  $-55$ °C to 125°C.

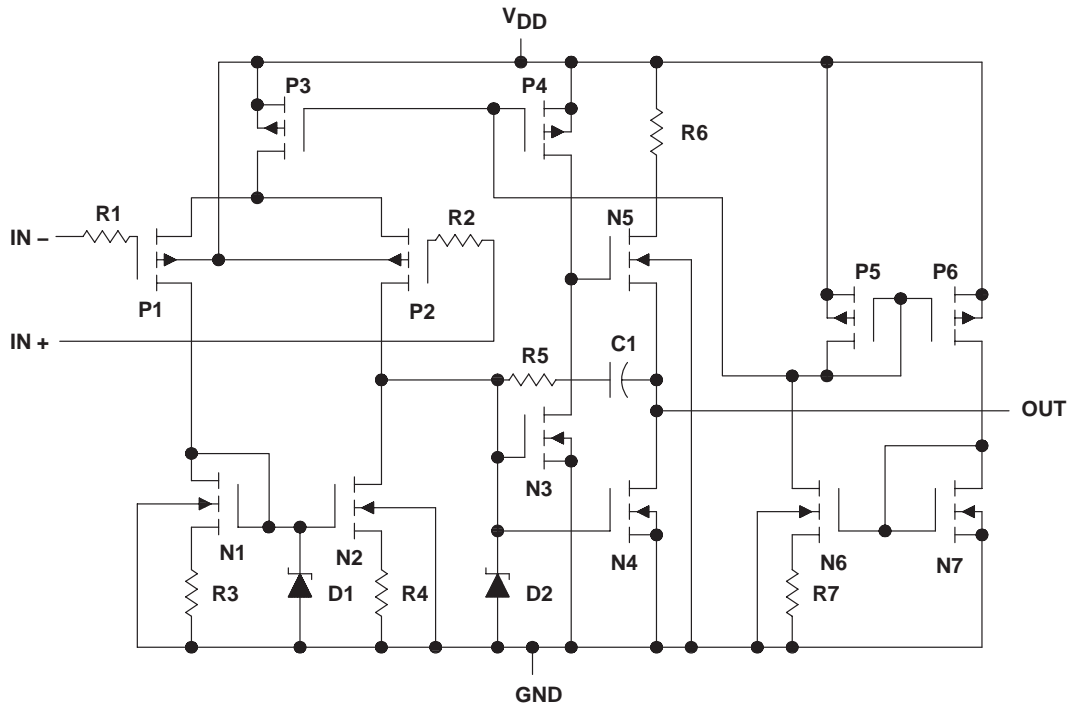


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equivalent schematic (each amplifier)



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## absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, $V_{DD}$ (see Note 1)	18 V
Differential input voltage, $V_{ID}$ (see Note 2)	$\pm V_{DD}$
Input voltage range, $V_I$ (any input)	-0.3 V to $V_{DD}$
Input current, $I_I$	$\pm 5$ mA
Output current, $I_O$ (each output)	$\pm 30$ mA
Total current into $V_{DD}$	45 mA
Total current out of GND	45 mA
Duration of short-circuit current at (or below) 25°C (see Note 3)	Unlimited
Continuous total dissipation	See Dissipation Rating Table
Operating free-air temperature, $T_A$ : C suffix	0°C to 70°C
I suffix	-40°C to 85°C
M suffix	-55°C to 125°C
Storage temperature range	-65°C to 150°C
Case temperature for 60 seconds: FK package	260°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: D or P package	260°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds: JG package	300°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

- NOTES: 1. All voltage values, except differential voltages, are with respect to network ground.  
 2. Differential voltages are at  $IN+$  with respect to  $IN-$ .  
 3. The output may be shorted to either supply. Temperature and/or supply voltages must be limited to ensure that the maximum dissipation rating is not exceeded (see application section).

DISSIPATION RATING TABLE

PACKAGE	$T_A \leq 25^\circ\text{C}$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25^\circ\text{C}$	$T_A = 70^\circ\text{C}$ POWER RATING	$T_A = 85^\circ\text{C}$ POWER RATING	$T_A = 125^\circ\text{C}$ POWER RATING
D	725 mW	5.8 mW/°C	464 mW	377 mW	
FK	1375 mW	11.0 mW/°C	880 mW	715 mW	275 mW
JG	1050 mW	8.4 mW/°C	672 mW	546 mW	210 mW
P	1000 mW	8.0 mW/°C	640 mW	520 mW	

## recommended operating conditions

	C SUFFIX		I SUFFIX		M SUFFIX		UNIT
	MIN	MAX	MIN	MAX	MIN	MAX	
Supply voltage, $V_{DD}$	3	16	4	16	4	16	V
Common-mode input voltage, $V_{IC}$	$V_{DD} = 5$ V		-0.2	3.5	-0.2	3.5	V
	$V_{DD} = 10$ V		-0.2	8.5	-0.2	8.5	
Operating free-air temperature, $T_A$	0	70	-40	85	-55	125	°C



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**electrical characteristics at specified free-air temperature,  $V_{DD} = 5\text{ V}$  (unless otherwise noted)**

PARAMETER		TEST CONDITIONS		$T_A$ †	TLC27M2C TLC27M2AC TLC27M2BC TLC27M7C			UNIT
					MIN	TYP	MAX	
$V_{IO}$	Input offset voltage	TLC27M2C	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$	$V_{IC} = 0$ , $R_I = 100\text{ k}\Omega$	25°C	1.1	10	mV
					Full range		12	
		TLC27M2AC	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$	$V_{IC} = 0$ , $R_I = 100\text{ k}\Omega$	25°C	0.9	5	mV
					Full range		6.5	
		TLC27M2BC	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$	$V_{IC} = 0$ , $R_I = 100\text{ k}\Omega$	25°C	220	2000	$\mu\text{V}$
					Full range		3000	
		TLC27M7C	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$	$V_{IC} = 0$ , $R_I = 100\text{ k}\Omega$	25°C	185	500	$\mu\text{V}$
					Full range		1500	
$\alpha_{VIO}$	Average temperature coefficient of input offset voltage			25°C to 70°C	1.7		$\mu\text{V}/^\circ\text{C}$	
$I_{IO}$	Input offset current (see Note 4)	$V_O = 2.5\text{ V}$	$V_{IC} = 2.5\text{ V}$	25°C	0.1	60	pA	
				70°C	7	300		
$I_{IB}$	Input bias current (see Note 4)	$V_O = 2.5\text{ V}$	$V_{IC} = 2.5\text{ V}$	25°C	0.6	60	pA	
				70°C	40	600		
$V_{ICR}$	Common-mode input voltage range (see Note 5)			25°C	-0.2 to 4	-0.3 to 4.2	V	
				Full range	-0.2 to 3.5		V	
$V_{OH}$	High-level output voltage	$V_{ID} = 100\text{ mV}$	$R_L = 100\text{ k}\Omega$	25°C	3.2	3.9	V	
				0°C	3	3.9		
				70°C	3	4		
$V_{OL}$	Low-level output voltage	$V_{ID} = -100\text{ mV}$	$I_{OL} = 0$	25°C	0	50	mV	
				0°C	0	50		
				70°C	0	50		
$A_{VD}$	Large-signal differential voltage amplification	$V_O = 0.25\text{ V to }2\text{ V}$	$R_L = 100\text{ k}\Omega$	25°C	25	170	V/mV	
				0°C	15	200		
				70°C	15	140		
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICRmin}$		25°C	65	91	dB	
				0°C	60	91		
				70°C	60	92		
$k_{SVR}$	Supply-voltage rejection ratio ( $\Delta V_{DD}/\Delta V_{IO}$ )	$V_{DD} = 5\text{ V to }10\text{ V}$	$V_O = 1.4\text{ V}$	25°C	70	93	dB	
				0°C	60	92		
				70°C	60	94		
$I_{DD}$	Supply current (two amplifiers)	$V_O = 2.5\text{ V}$ , No load	$V_{IC} = 2.5\text{ V}$	25°C	210	560	$\mu\text{A}$	
				0°C	250	640		
				70°C	170	440		

† Full range is 0°C to 70°C.

- NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.  
5. This range also applies to each input individually.



# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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electrical characteristics at specified free-air temperature,  $V_{DD} = 10\text{ V}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS		$T_A$ †	TLC27M2C TLC27M2AC TLC27M2BC TLC27M7C			UNIT
					MIN	TYP	MAX	
$V_{IO}$	Input offset voltage	TLC27M2C	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	1.1	10	mV
					Full range		12	
		TLC27M2AC	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	0.9	5	
					Full range		6.5	
	TLC27M2BC	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	224	2000	$\mu\text{V}$	
				Full range		3000		
	TLC27M7C	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	190	800		
				Full range		1900		
$\alpha_{VIO}$	Average temperature coefficient of input offset voltage			25°C to 70°C	2.1		$\mu\text{V}/^\circ\text{C}$	
$I_{IO}$	Input offset current (see Note 4)	$V_O = 5\text{ V}$ ,	$V_{IC} = 5\text{ V}$	25°C	0.1	60	pA	
				70°C	7	300		
$I_{IB}$	Input bias current (see Note 4)	$V_O = 5\text{ V}$ ,	$V_{IC} = 5\text{ V}$	25°C	0.7	60	pA	
				70°C	50	600		
$V_{ICR}$	Common-mode input voltage range (see Note 5)			25°C	-0.2 to 9	-0.3 to 9.2	V	
				Full range	-0.2 to 8.5		V	
$V_{OH}$	High-level output voltage	$V_{ID} = 100\text{ mV}$ ,	$R_L = 100\text{ k}\Omega$	25°C	8	8.7	V	
				0°C	7.8	8.7		
				70°C	7.8	8.7		
$V_{OL}$	Low-level output voltage	$V_{ID} = -100\text{ mV}$ ,	$I_{OL} = 0$	25°C	0	50	mV	
				0°C	0	50		
				70°C	0	50		
$A_{VD}$	Large-signal differential voltage amplification	$V_O = 1\text{ V to }6\text{ V}$ ,	$R_L = 100\text{ k}\Omega$	25°C	25	275	V/mV	
				0°C	15	320		
				70°C	15	230		
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICRmin}$		25°C	65	94	dB	
				0°C	60	94		
				70°C	60	94		
$k_{SVR}$	Supply-voltage rejection ratio ( $\Delta V_{DD}/\Delta V_{IO}$ )	$V_{DD} = 5\text{ V to }10\text{ V}$ ,	$V_O = 1.4\text{ V}$	25°C	70	93	dB	
				0°C	60	92		
				70°C	60	94		
$I_{DD}$	Supply current (two amplifiers)	$V_O = 5\text{ V}$ , No load	$V_{IC} = 5\text{ V}$ ,	25°C	285	600	$\mu\text{A}$	
				0°C	345	800		
				70°C	220	560		

† Full range is 0°C to 70°C.

- NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.  
5. This range also applies to each input individually.



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**electrical characteristics at specified free-air temperature,  $V_{DD} = 5\text{ V}$  (unless otherwise noted)**

PARAMETER		TEST CONDITIONS		$T_A$ †	TLC27M2I TLC27M2AI TLC27M2BI TLC27M7I			UNIT
					MIN	TYP	MAX	
$V_{IO}$	Input offset voltage	TLC27M2I	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	1.1	10	mV
					Full range		13	
		TLC27M2AI	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	0.9	5	mV
					Full range		7	
		TLC27M2BI	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	220	2000	$\mu\text{V}$
					Full range		3500	
		TLC27M7I	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	185	500	$\mu\text{V}$
					Full range		2000	
$\alpha_{VIO}$	Average temperature coefficient of input offset voltage			25°C to 85°C	1.7		$\mu\text{V}/^\circ\text{C}$	
$I_{IO}$	Input offset current (see Note 4)	$V_O = 2.5\text{ V}$ ,	$V_{IC} = 2.5\text{ V}$	25°C	0.1	60	pA	
				85°C	24	1000		
$I_{IB}$	Input bias current (see Note 4)	$V_O = 2.5\text{ V}$ ,	$V_{IC} = 2.5\text{ V}$	25°C	0.6	60	pA	
				85°C	200	2000		
$V_{ICR}$	Common-mode input voltage range (see Note 5)			25°C	-0.2 to 4	-0.3 to 4.2	V	
				Full range	-0.2 to 3.5		V	
$V_{OH}$	High-level output voltage	$V_{ID} = 100\text{ mV}$ ,	$R_L = 100\text{ k}\Omega$	25°C	3.2	3.9	V	
				-40°C	3	3.9		
				85°C	3	4		
$V_{OL}$	Low-level output voltage	$V_{ID} = -100\text{ mV}$ ,	$I_{OL} = 0$	25°C	0	50	mV	
				-40°C	0	50		
				85°C	0	50		
$A_{VD}$	Large-signal differential voltage amplification	$V_O = 0.25\text{ V to }2\text{ V}$ ,	$R_L = 100\text{ k}\Omega$	25°C	25	170	V/mV	
				-40°C	15	270		
				85°C	15	130		
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICR\text{min}}$		25°C	65	91	dB	
				-40°C	60	90		
				85°C	60	90		
$k_{SVR}$	Supply-voltage rejection ratio ( $\Delta V_{DD}/\Delta V_{IO}$ )	$V_{DD} = 5\text{ V to }10\text{ V}$ ,	$V_O = 1.4\text{ V}$	25°C	70	93	dB	
				-40°C	60	91		
				85°C	60	94		
$I_{DD}$	Supply current (two amplifiers)	$V_O = 2.5\text{ V}$ , No load	$V_{IC} = 2.5\text{ V}$ ,	25°C	210	560	$\mu\text{A}$	
				-40°C	315	800		
				85°C	160	400		

† Full range is -40°C to 85°C.

- NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.  
5. This range also applies to each input individually.



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electrical characteristics at specified free-air temperature,  $V_{DD} = 10\text{ V}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS		$T_A$ †	TLC27M2I TLC27M2AI TLC27M2BI TLC27M7I			UNIT
					MIN	TYP	MAX	
$V_{IO}$	Input offset voltage	TLC27M2I	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	1.1	10	mV
					Full range		13	
		TLC27M2AI	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	0.9	5	
					Full range		7	
	TLC27M2BI	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	224	2000	$\mu\text{V}$	
				Full range		3500		
	TLC27M7I	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	190	800		
				Full range		2900		
$\alpha_{VIO}$	Average temperature coefficient of input offset voltage			25°C to 85°C	2.1		$\mu\text{V}/^\circ\text{C}$	
$I_{IO}$	Input offset current (see Note 4)	$V_O = 5\text{ V}$	$V_{IC} = 5\text{ V}$	25°C	0.1	60	pA	
				85°C	26	1000		
$I_{IB}$	Input bias current (see Note 4)	$V_O = 5\text{ V}$	$V_{IC} = 5\text{ V}$	25°C	0.7	60	pA	
				85°C	220	200 0		
$V_{ICR}$	Common-mode input voltage range (see Note 5)			25°C	-0.2 to 9	-0.3 to 9.2	V	
				Full range	-0.2 to 8.5		V	
$V_{OH}$	High-level output voltage	$V_{ID} = 100\text{ mV}$	$R_L = 100\text{ k}\Omega$	25°C	8	8.7	V	
				-40°C	7.8	8.7		
				85°C	7.8	8.7		
$V_{OL}$	Low-level output voltage	$V_{ID} = -100\text{ mV}$	$I_{OL} = 0$	25°C	0	50	mV	
				-40°C	0	50		
				85°C	0	50		
$A_{VD}$	Large-signal differential voltage amplification	$V_O = 1\text{ V to }6\text{ V}$	$R_L = 100\text{ k}\Omega$	25°C	25	275	V/mV	
				-40°C	15	390		
				85°C	15	220		
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICRmin}$		25°C	65	94	dB	
				-40°C	60	93		
				85°C	60	94		
$k_{SVR}$	Supply-voltage rejection ratio ( $\Delta V_{DD}/\Delta V_{IO}$ )	$V_{DD} = 5\text{ V to }10\text{ V}$	$V_O = 1.4\text{ V}$	25°C	70	93	dB	
				-40°C	60	91		
				85°C	60	94		
$I_{DD}$	Supply current	$V_O = 5\text{ V}$ , No load	$V_{IC} = 5\text{ V}$	25°C	285	600	$\mu\text{A}$	
				-40°C	450	900		
				85°C	205	520		

† Full range is -40°C to 85°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.  
5. This range also applies to each input individually.



# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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**electrical characteristics at specified free-air temperature,  $V_{DD} = 5\text{ V}$  (unless otherwise noted)**

PARAMETER		TEST CONDITIONS	$T_A$ †	TLC27M2M TLC27M7M			UNIT
				MIN	TYP	MAX	
$V_{IO}$	Input offset voltage	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	1.1	10	mV
				Full range		12	
				25°C	185	500	
				Full range		3750	
$\alpha_{VIO}$	Average temperature coefficient of input offset voltage		25°C to 125°C	1.7		$\mu\text{V}/^\circ\text{C}$	
$I_{IO}$	Input offset current (see Note 4)	$V_O = 2.5\text{ V}$ ,	$V_{IC} = 2.5\text{ V}$	25°C	0.1	60	pA
				125°C	1.4	15	nA
$I_{IB}$	Input bias current (see Note 4)	$V_O = 2.5\text{ V}$ ,	$V_{IC} = 2.5\text{ V}$	25°C	0.6	60	pA
				125°C	9	35	nA
$V_{ICR}$	Common-mode input voltage range (see Note 5)			25°C	0 to 4	-0.3 to 4.2	V
				Full range	0 to 3.5		V
$V_{OH}$	High-level output voltage	$V_{ID} = 100\text{ mV}$ ,	$R_L = 100\text{ k}\Omega$	25°C	3.2	3.9	V
				-55°C	3	3.9	
				125°C	3	4	
$V_{OL}$	Low-level output voltage	$V_{ID} = -100\text{ mV}$ ,	$I_{OL} = 0$	25°C	0	50	mV
				-55°C	0	50	
				125°C	0	50	
$A_{VD}$	Large-signal differential voltage amplification	$V_O = 0.25\text{ V to }2\text{ V}$ ,	$R_L = 100\text{ k}\Omega$	25°C	25	170	V/mV
				-55°C	15	290	
				125°C	15	120	
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICRmin}$		25°C	65	91	dB
				-55°C	60	89	
				125°C	60	91	
$k_{SVR}$	Supply-voltage rejection ratio ( $\Delta V_{DD}/\Delta V_{IO}$ )	$V_{DD} = 5\text{ V to }10\text{ V}$ ,	$V_O = 1.4\text{ V}$	25°C	70	93	dB
				-55°C	60	91	
				125°C	60	94	
$I_{DD}$	Supply current (two amplifiers)	$V_O = 2.5\text{ V}$ , No load	$V_{IC} = 2.5\text{ V}$ ,	25°C	210	560	$\mu\text{A}$
				-55°C	340	880	
				125°C	140	360	

† Full range is -55°C to 125°C.

- NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.  
5. This range also applies to each input individually.

# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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electrical characteristics at specified free-air temperature,  $V_{DD} = 10\text{ V}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	$T_A^\dagger$	TLC27M2M TLC27M7M			UNIT	
				MIN	TYP	MAX		
$V_{IO}$	Input offset voltage	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	1.1	10	mV	
				Full range		12		
		TLC27M7M	$V_O = 1.4\text{ V}$ , $R_S = 50\ \Omega$ ,	$V_{IC} = 0$ , $R_L = 100\text{ k}\Omega$	25°C	190		800
					Full range			4300
$\alpha_{VIO}$	Average temperature coefficient of input offset voltage		25°C to 125°C	2.1		$\mu\text{V}/^\circ\text{C}$		
$I_{IO}$	Input offset current (see Note 4)	$V_O = 5\text{ V}$ ,	$V_{IC} = 5\text{ V}$	25°C	0.1	60	pA	
				125°C	1.8	15		
$I_{IB}$	Input bias current (see Note 4)	$V_O = 5\text{ V}$ ,	$V_{IC} = 5\text{ V}$	25°C	0.7	60	pA	
				125°C	10	35		
$V_{ICR}$	Common-mode input voltage range (see Note 5)			25°C	0 to 9	-0.3 to 9.2	V	
				Full range	0 to 8.5		V	
$V_{OH}$	High-level output voltage	$V_{ID} = 100\text{ mV}$ ,	$R_L = 100\text{ k}\Omega$	25°C	8	8.7	V	
				-55°C	7.8	8.6		
				125°C	7.8	8.8		
$V_{OL}$	Low-level output voltage	$V_{ID} = -100\text{ mV}$ ,	$I_{OL} = 0$	25°C	0	50	mV	
				-55°C	0	50		
				125°C	0	50		
$A_{VD}$	Large-signal differential voltage amplification	$V_O = 1\text{ V to }6\text{ V}$ ,	$R_L = 100\text{ k}\Omega$	25°C	25	275	V/mV	
				-55°C	15	420		
				125°C	15	190		
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICRmin}$		25°C	65	94	dB	
				-55°C	60	93		
				125°C	60	93		
$k_{SVR}$	Supply-voltage rejection ratio ( $\Delta V_{DD}/\Delta V_{IO}$ )	$V_{DD} = 5\text{ V to }10\text{ V}$ ,	$V_O = 1.4\text{ V}$	25°C	70	93	dB	
				-55°C	60	91		
				125°C	60	94		
$I_{DD}$	Supply current (two amplifiers)	$V_O = 5\text{ V}$ , No load	$V_{IC} = 5\text{ V}$ ,	25°C	285	600	$\mu\text{A}$	
				-55°C	490	1000		
				125°C	180	480		

$^\dagger$  Full range is -55°C to 125°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.  
5. This range also applies to each input individually.



# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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## operating characteristics at specified free-air temperature, $V_{DD} = 5\text{ V}$

PARAMETER	TEST CONDITIONS	$T_A$	TLC27M2C TLC27M2AC TLC27M2BC TLC27M7C			UNIT
			MIN	TYP	MAX	
SR    Slew rate at unity gain	$R_L = 100\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , See Figure 1	$V_{I(PP)} = 1\text{ V}$	25°C	0.43		V/ $\mu$ s
			0°C	0.46		
			70°C	0.36		
		$V_{I(PP)} = 2.5\text{ V}$	25°C	0.40		
			0°C	0.43		
			70°C	0.34		
$V_n$ Equivalent input noise voltage	$f = 1\text{ kHz}$ , See Figure 2	$R_S = 20\ \Omega$ , 25°C	32		nV/ $\sqrt{\text{Hz}}$	
$B_{OM}$ Maximum output-swing bandwidth	$V_O = V_{OH}$ , $R_L = 100\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , See Figure 1	25°C	55		kHz	
		0°C	60			
		70°C	50			
$B_1$ Unity-gain bandwidth	$V_I = 10\text{ mV}$ , See Figure 3	$C_L = 20\text{ pF}$ , 25°C	525		kHz	
			0°C	600		
			70°C	400		
$\phi_m$ Phase margin	$V_I = 10\text{ mV}$ , $C_L = 20\text{ pF}$ , $f = B_1$ , See Figure 3	25°C	40°			
		0°C	41°			
		70°C	39°			

## operating characteristics at specified free-air temperature, $V_{DD} = 10\text{ V}$

PARAMETER	TEST CONDITIONS	$T_A$	TLC27M2C TLC27M2AC TLC27M2BC TLC27M7C			UNIT
			MIN	TYP	MAX	
SR    Slew rate at unity gain	$R_L = 100\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , See Figure 1	$V_{I(PP)} = 1\text{ V}$	25°C	0.62		V/ $\mu$ s
			0°C	0.67		
			70°C	0.51		
		$V_{I(PP)} = 5.5\text{ V}$	25°C	0.56		
			0°C	0.61		
			70°C	0.46		
$V_n$ Equivalent input noise voltage	$f = 1\text{ kHz}$ , See Figure 2	$R_S = 20\ \Omega$ , 25°C	32		nV/ $\sqrt{\text{Hz}}$	
$B_{OM}$ Maximum output-swing bandwidth	$V_O = V_{OH}$ , $R_L = 100\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , See Figure 1	25°C	35		kHz	
		0°C	40			
		70°C	30			
$B_1$ Unity-gain bandwidth	$V_I = 10\text{ mV}$ , See Figure 3	$C_L = 20\text{ pF}$ , 25°C	635		kHz	
			0°C	710		
			70°C	510		
$\phi_m$ Phase margin	$V_I = 10\text{ mV}$ , $C_L = 20\text{ pF}$ , $f = B_1$ , See Figure 3	25°C	43°			
		0°C	44°			
		70°C	42°			



# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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## operating characteristics at specified free-air temperature, $V_{DD} = 5\text{ V}$

PARAMETER	TEST CONDITIONS		$T_A$	TLC27M2I TLC27M2AI TLC27M2BI TLC27M7I			UNIT
				MIN	TYP	MAX	
SR Slew rate at unity gain	$R_L = 100\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , See Figure 1	$V_{I(PP)} = 1\text{ V}$	25°C	0.43			V/ $\mu$ s
			-40°C	0.51			
			85°C	0.35			
		$V_{I(PP)} = 2.5\text{ V}$	25°C	0.40			
			-40°C	0.48			
			85°C	0.32			
$V_n$ Equivalent input noise voltage	$f = 1\text{ kHz}$ , See Figure 2	$R_S = 20\ \Omega$	25°C	32			nV/ $\sqrt{\text{Hz}}$
$B_{OM}$ Maximum output-swing bandwidth	$V_O = V_{OH}$ , $R_L = 100\text{ k}\Omega$	$C_L = 20\text{ pF}$ , See Figure 1	25°C	55			kHz
			-40°C	75			
			85°C	45			
$B_1$ Unity-gain bandwidth	$V_I = 10\text{ mV}$ , See Figure 3	$C_L = 20\text{ pF}$	25°C	525			kHz
			-40°C	770			
			85°C	370			
$\phi_m$ Phase margin	$V_I = 10\text{ mV}$ , $C_L = 20\text{ pF}$	$f = B_1$ , See Figure 3	25°C	40°			
			-40°C	43°			
			85°C	38°			

## operating characteristics at specified free-air temperature, $V_{DD} = 10\text{ V}$

PARAMETER	TEST CONDITIONS		$T_A$	TLC27M2I TLC27M2AI TLC27M2BI TLC27M7I			UNIT
				MIN	TYP	MAX	
SR Slew rate at unity gain	$R_L = 100\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , See Figure 1	$V_{I(PP)} = 1\text{ V}$	25°C	0.62			V/ $\mu$ s
			-40°C	0.77			
			85°C	0.47			
		$V_{I(PP)} = 5.5\text{ V}$	25°C	0.56			
			-40°C	0.70			
			85°C	0.44			
$V_n$ Equivalent input noise voltage	$f = 1\text{ kHz}$ , See Figure 2	$R_S = 20\ \Omega$	25°C	32			nV/ $\sqrt{\text{Hz}}$
$B_{OM}$ Maximum output-swing bandwidth	$V_O = V_{OH}$ , $R_L = 100\text{ k}\Omega$	$C_L = 20\text{ pF}$ , See Figure 1	25°C	35			kHz
			-40°C	45			
			85°C	25			
$B_1$ Unity-gain bandwidth	$V_I = 10\text{ mV}$ , See Figure 3	$C_L = 20\text{ pF}$	25°C	635			kHz
			-40°C	880			
			85°C	480			
$\phi_m$ Phase margin	$V_I = 10\text{ mV}$ , $C_L = 20\text{ pF}$	$f = B_1$ , See Figure 3	25°C	43°			
			-40°C	46°			
			85°C	41°			



# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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## operating characteristics at specified free-air temperature, $V_{DD} = 5\text{ V}$

PARAMETER	TEST CONDITIONS	$T_A$	TLC27M2M TLC27M7M			UNIT
			MIN	TYP	MAX	
SR    Slew rate at unity gain	$R_L = 100\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , See Figure 1	$V_{I(PP)} = 1\text{ V}$	25°C	0.43		V/ $\mu$ s
			-55°C	0.54		
			125°C	0.29		
		$V_{I(PP)} = 2.5\text{ V}$	25°C	0.40		
			-55°C	0.49		
			125°C	0.28		
$V_n$ Equivalent input noise voltage	$f = 1\text{ kHz}$ , See Figure 2	$R_S = 20\ \Omega$ , 25°C	32		nV/ $\sqrt{\text{Hz}}$	
$B_{OM}$ Maximum output-swing bandwidth	$V_O = V_{OH}$ , $R_L = 100\text{ k}\Omega$ , See Figure 1	$C_L = 20\text{ pF}$ , See Figure 1	25°C	55		kHz
			-55°C	80		
			125°C	40		
$B_1$ Unity-gain bandwidth	$V_I = 10\text{ mV}$ , See Figure 3	$C_L = 20\text{ pF}$ , See Figure 3	25°C	525		kHz
			-55°C	850		
			125°C	330		
$\phi_m$ Phase margin	$V_I = 10\text{ mV}$ , $C_L = 20\text{ pF}$ , See Figure 3	$f = B_1$ , See Figure 3	25°C	40°		
			-55°C	44°		
			125°C	36°		

## operating characteristics at specified free-air temperature, $V_{DD} = 10\text{ V}$

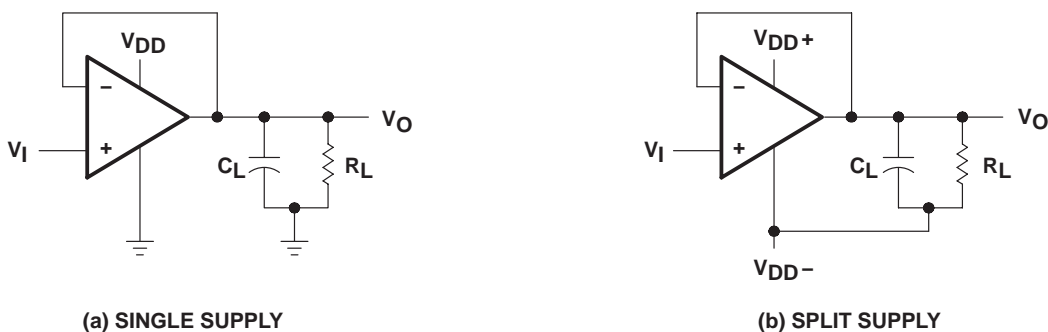
PARAMETER	TEST CONDITIONS	$T_A$	TLC27M2M TLC27M7M			UNIT
			MIN	TYP	MAX	
SR    Slew rate at unity gain	$R_L = 100\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , See Figure 1	$V_{I(PP)} = 1\text{ V}$	25°C	0.62		V/ $\mu$ s
			-55°C	0.81		
			125°C	0.38		
		$V_{I(PP)} = 5.5\text{ V}$	25°C	0.56		
			-55°C	0.73		
			125°C	0.35		
$V_n$ Equivalent input noise voltage	$f = 1\text{ kHz}$ , See Figure 2	$R_S = 20\ \Omega$ , 25°C	32		nV/ $\sqrt{\text{Hz}}$	
$B_{OM}$ Maximum output-swing bandwidth	$V_O = V_{OH}$ , $R_L = 100\text{ k}\Omega$ , See Figure 1	$C_L = 20\text{ pF}$ , See Figure 1	25°C	35		kHz
			-55°C	50		
			125°C	20		
$B_1$ Unity gain bandwidth	$V_I = 10\text{ mV}$ , See Figure 3	$C_L = 20\text{ pF}$ , See Figure 3	25°C	635		kHz
			-55°C	960		
			125°C	440		
$\phi_m$ Phase margin	$V_I = 10\text{ mV}$ , $C_L = 20\text{ pF}$ , See Figure 3	$f = B_1$ , See Figure 3	25°C	43°		
			-55°C	47°		
			125°C	39°		



**PARAMETER MEASUREMENT INFORMATION**

**single-supply versus split-supply test circuits**

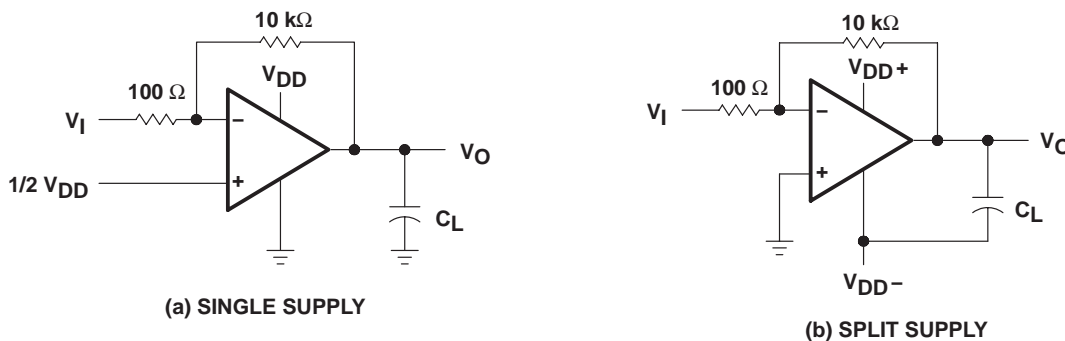
Because the TLC27M2 and TLC27M7 are optimized for single-supply operation, circuit configurations used for the various tests often present some inconvenience since the input signal, in many cases, must be offset from ground. This inconvenience can be avoided by testing the device with split supplies and the output load tied to the negative rail. A comparison of single-supply versus split-supply test circuits is shown below. The use of either circuit gives the same result.



**Figure 1. Unity-Gain Amplifier**



**Figure 2. Noise-Test Circuit**



**Figure 3. Gain-of-100 Inverting Amplifier**

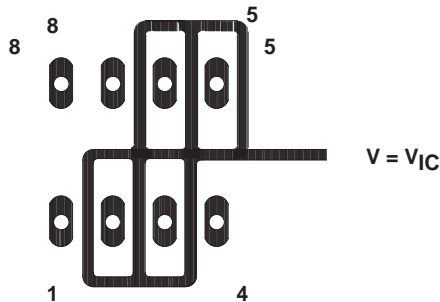
## PARAMETER MEASUREMENT INFORMATION

### input bias current

Because of the high input impedance of the TLC27M2 and TLC27M7 operational amplifiers, attempts to measure the input bias current can result in erroneous readings. The bias current at normal room ambient temperature is typically less than 1 pA, a value that is easily exceeded by leakages on the test socket. Two suggestions are offered to avoid erroneous measurements:

1. Isolate the device from other potential leakage sources. Use a grounded shield around and between the device inputs (see Figure 4). Leakages that would otherwise flow to the inputs are shunted away.
2. Compensate for the leakage of the test socket by actually performing an input bias current test (using a picoammeter) with no device in the test socket. The actual input bias current can then be calculated by subtracting the open-socket leakage readings from the readings obtained with a device in the test socket.

One word of caution—many automatic testers as well as some bench-top operational amplifier testers use the servo-loop technique with a resistor in series with the device input to measure the input bias current (the voltage drop across the series resistor is measured and the bias current is calculated). This method requires that a device be inserted into the test socket to obtain a correct reading; therefore, an open-socket reading is not feasible using this method.



**Figure 4. Isolation Metal Around Device Inputs (JG and P packages)**

### low-level output voltage

To obtain low-supply-voltage operation, some compromise was necessary in the input stage. This compromise results in the device low-level output being dependent on both the common-mode input voltage level as well as the differential input voltage level. When attempting to correlate low-level output readings with those quoted in the electrical specifications, these two conditions should be observed. If conditions other than these are to be used, please refer to Figures 14 through 19 in the Typical Characteristics of this data sheet.

PARAMETER MEASUREMENT INFORMATION

input offset voltage temperature coefficient

Erroneous readings often result from attempts to measure temperature coefficient of input offset voltage. This parameter is actually a calculation using input offset voltage measurements obtained at two different temperatures. When one (or both) of the temperatures is below freezing, moisture can collect on both the device and the test socket. This moisture results in leakage and contact resistance, which can cause erroneous input offset voltage readings. The isolation techniques previously mentioned have no effect on the leakage, since the moisture also covers the isolation metal itself, thereby rendering it useless. It is suggested that these measurements be performed at temperatures above freezing to minimize error.

full-power response

Full-power response, the frequency above which the operational amplifier slew rate limits the output voltage swing, is often specified two ways: full-linear response and full-peak response. The full-linear response is generally measured by monitoring the distortion level of the output while increasing the frequency of a sinusoidal input signal until the maximum frequency is found above which the output contains significant distortion. The full-peak response is defined as the maximum output frequency, without regard to distortion, above which full peak-to-peak output swing cannot be maintained.

Because there is no industry-wide accepted value for significant distortion, the full-peak response is specified in this data sheet and is measured using the circuit of Figure 1. The initial setup involves the use of a sinusoidal input to determine the maximum peak-to-peak output of the device (the amplitude of the sinusoidal wave is increased until clipping occurs). The sinusoidal wave is then replaced with a square wave of the same amplitude. The frequency is then increased until the maximum peak-to-peak output can no longer be maintained (Figure 5). A square wave is used to allow a more accurate determination of the point at which the maximum peak-to-peak output is reached.

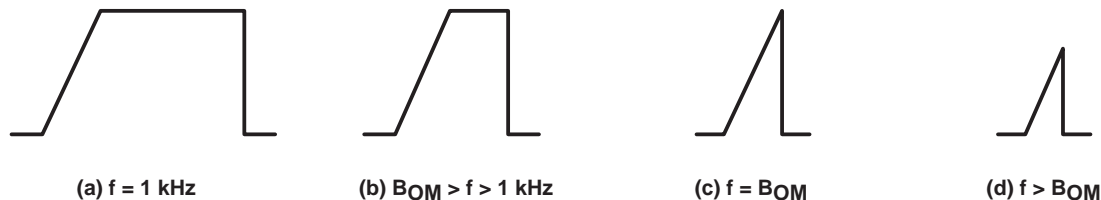


Figure 5. Full-Power-Response Output Signal

test time

Inadequate test time is a frequent problem, especially when testing CMOS devices in a high-volume, short-test-time environment. Internal capacitances are inherently higher in CMOS than in bipolar and BiFET devices and require longer test times than their bipolar and BiFET counterparts. The problem becomes more pronounced with reduced supply levels and lower temperatures.

# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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## TYPICAL CHARACTERISTICS

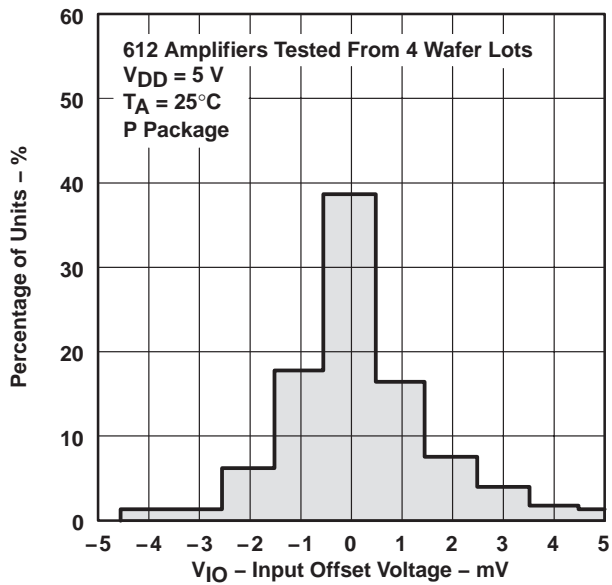
**Table of Graphs**

			FIGURE
$V_{IO}$	Input offset voltage	Distribution	6, 7
$\alpha_{VIO}$	Temperature coefficient	Distribution	8, 9
$V_{OH}$	High-level output voltage	vs High-level output current	10, 11
		vs Supply voltage	12
		vs Free-air temperature	13
$V_{OL}$	Low-level output voltage	vs Common-mode input voltage	14, 15
		vs Differential input voltage	16
		vs Free-air temperature	17
		vs Low-level output current	18, 19
$A_{VD}$	Differential voltage amplification	vs Supply voltage	20
		vs Free-air temperature	21
		vs Frequency	32, 33
$I_{IB}/I_{IO}$	Input bias and input offset current	vs Free-air temperature	22
$V_{IC}$	Common-mode input voltage	vs Supply voltage	23
$I_{DD}$	Supply current	vs Supply voltage	24
		vs Free-air temperature	25
SR	Slew rate	vs Supply voltage	26
		vs Free-air temperature	27
	Normalized slew rate	vs Free-air temperature	28
$V_{O(PP)}$	Maximum peak-to-peak output voltage	vs Frequency	29
$B_1$	Unity-gain bandwidth	vs Free-air temperature	30
		vs Supply voltage	31
$\phi_m$	Phase margin	vs Supply voltage	34
		vs Free-air temperature	35
		vs Capacitive loads	36
$V_n$	Equivalent input noise voltage	vs Frequency	37
$\phi$	Phase shift	vs Frequency	32, 33



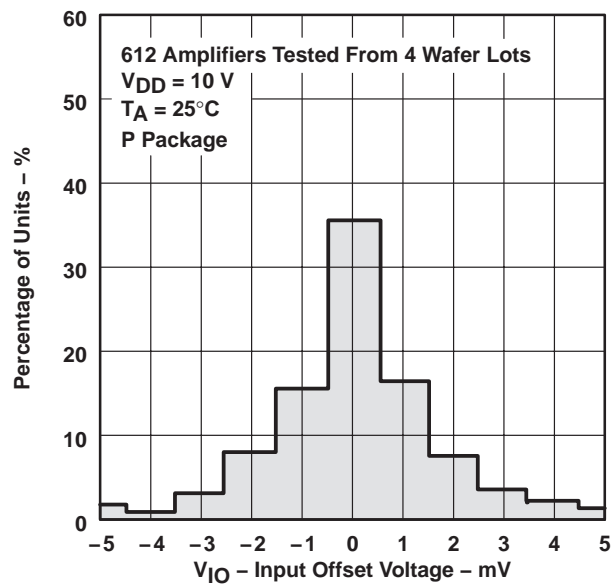
**TYPICAL CHARACTERISTICS**

**DISTRIBUTION OF TLC27M2  
 INPUT OFFSET VOLTAGE**



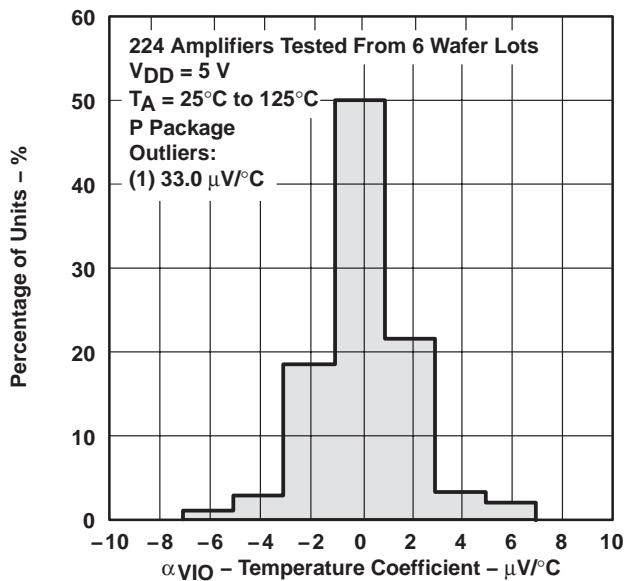
**Figure 6**

**DISTRIBUTION OF TLC27M2  
 INPUT OFFSET VOLTAGE**



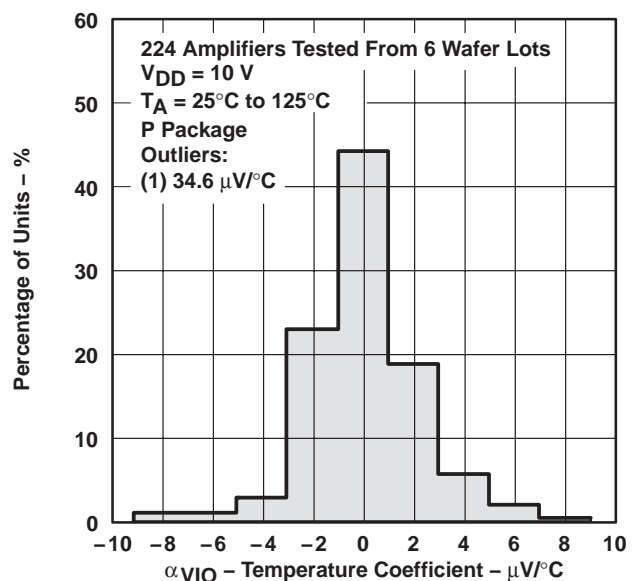
**Figure 7**

**DISTRIBUTION OF TLC27M2 AND TLC27M7  
 INPUT OFFSET VOLTAGE  
 TEMPERATURE COEFFICIENT**



**Figure 8**

**DISTRIBUTION OF TLC27M2 AND TLC27M7  
 INPUT OFFSET VOLTAGE  
 TEMPERATURE COEFFICIENT**



**Figure 9**

TYPICAL CHARACTERISTICS†

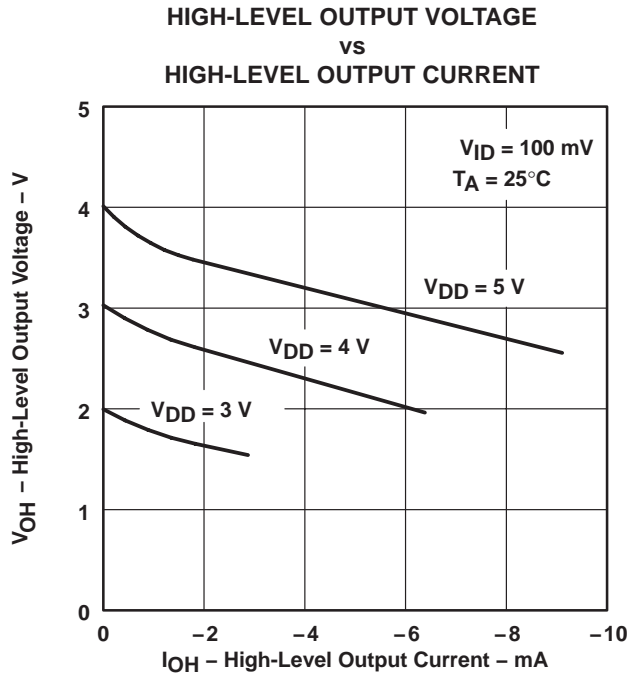


Figure 10

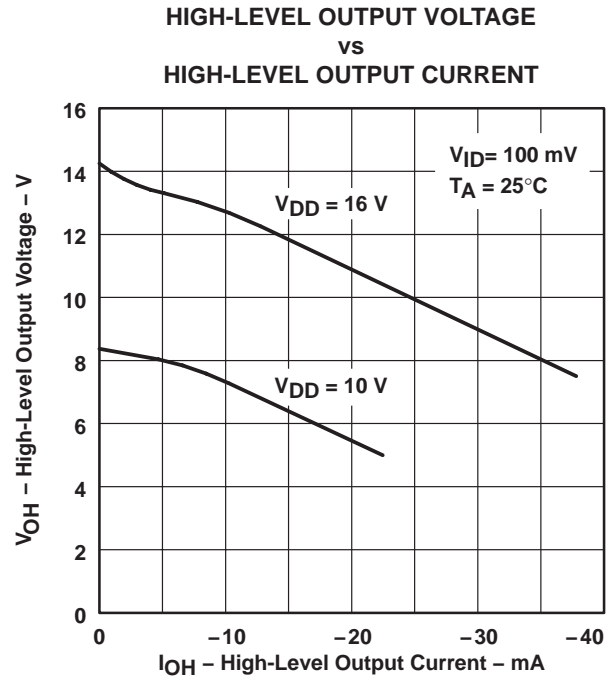


Figure 11



Figure 12

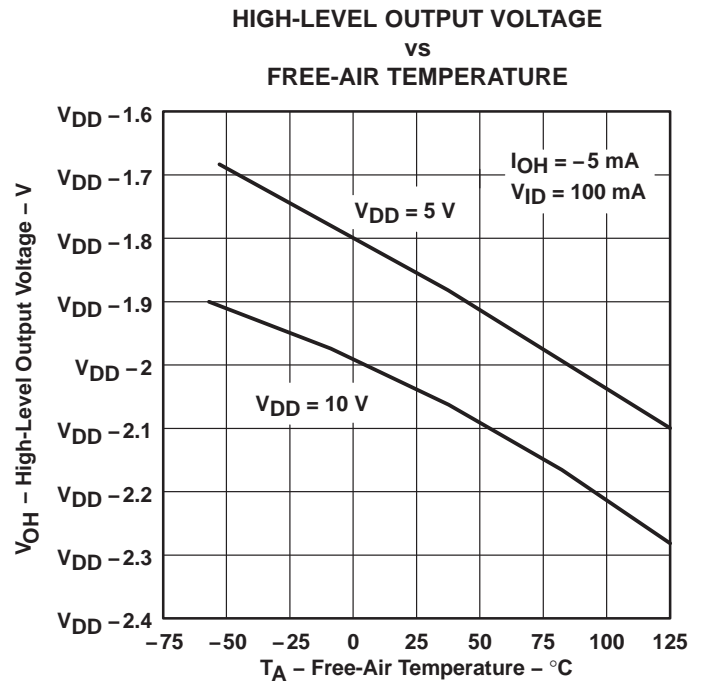


Figure 13

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†



Figure 14



Figure 15

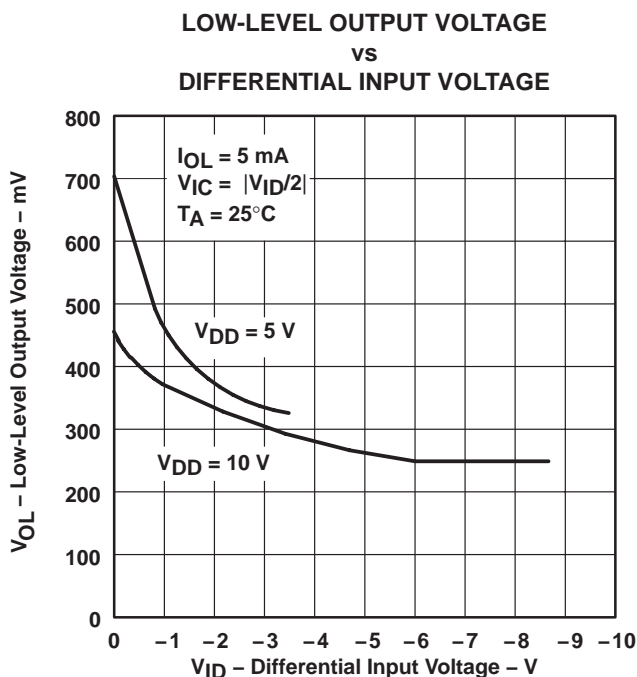


Figure 16



Figure 17

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†



Figure 18



Figure 19



Figure 20

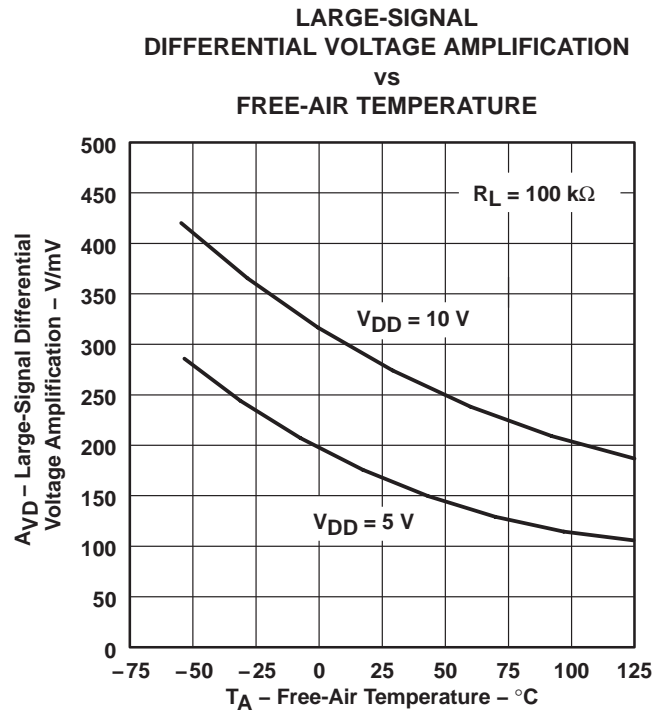


Figure 21

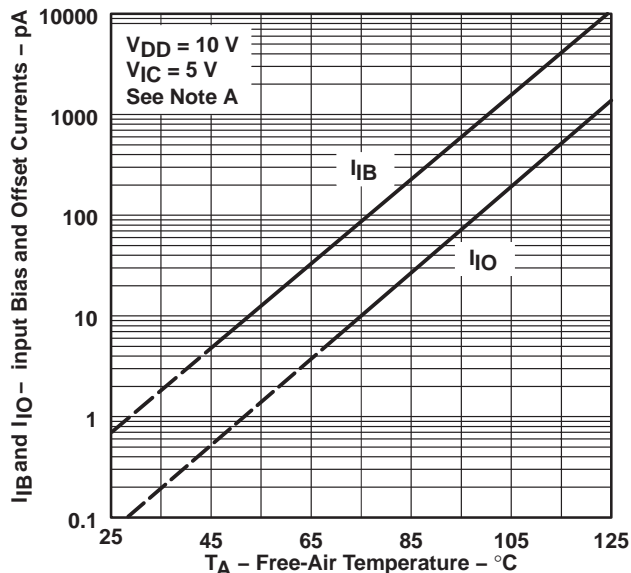
† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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## TYPICAL CHARACTERISTICS†

INPUT BIAS CURRENT AND INPUT OFFSET CURRENT  
vs  
FREE-AIR TEMPERATURE



NOTE A: The typical values of input bias current and input offset current below 5 pA were determined mathematically.

Figure 22

COMMON-MODE INPUT VOLTAGE POSITIVE LIMIT  
vs  
SUPPLY VOLTAGE

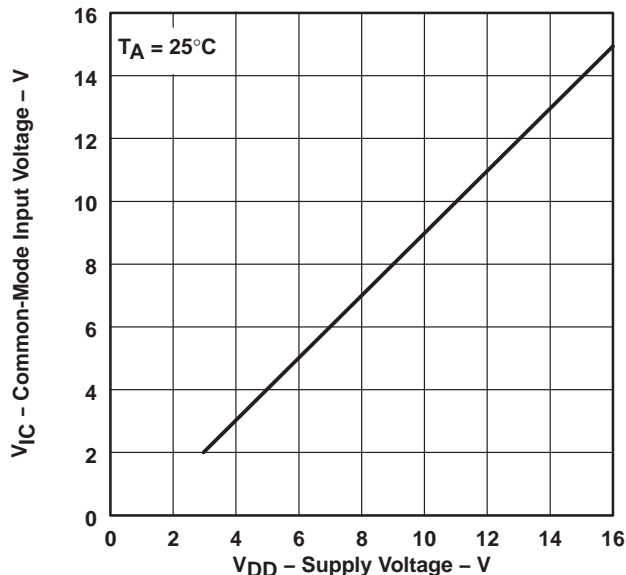


Figure 23

SUPPLY CURRENT  
vs  
SUPPLY VOLTAGE

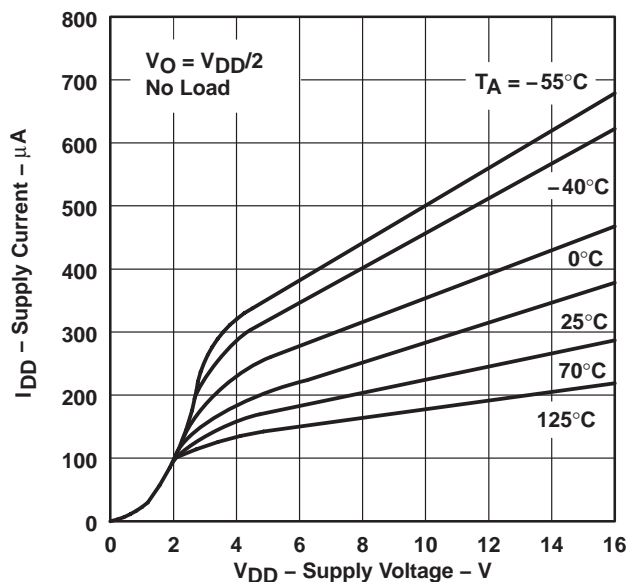


Figure 24

SUPPLY CURRENT  
vs  
FREE-AIR TEMPERATURE

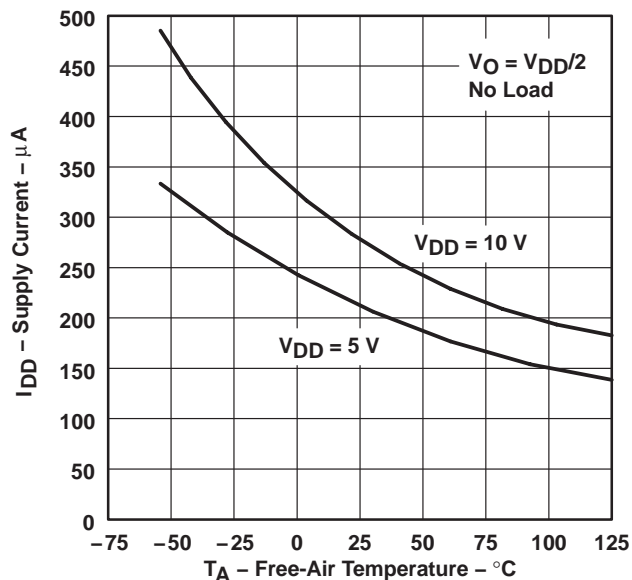


Figure 25

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.



TYPICAL CHARACTERISTICS†

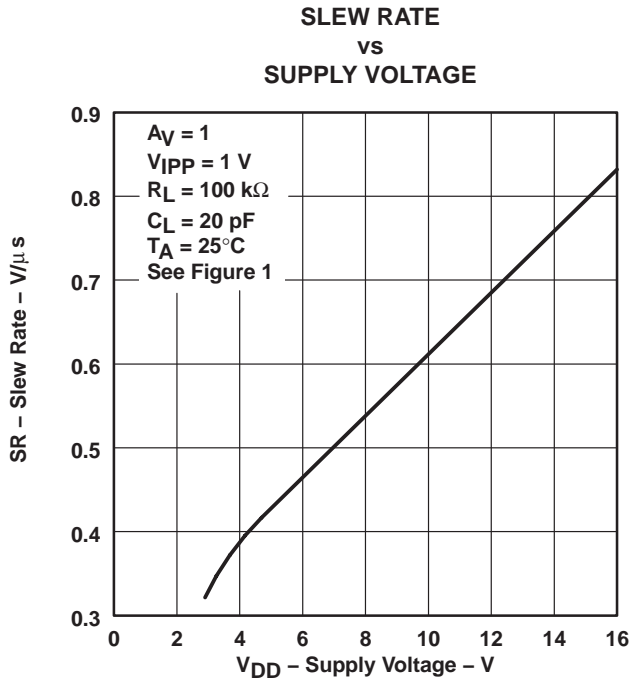


Figure 26

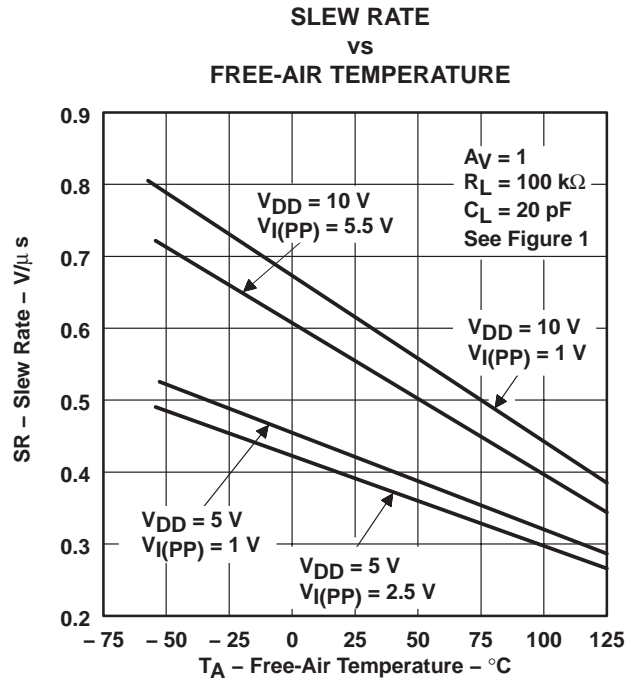


Figure 27

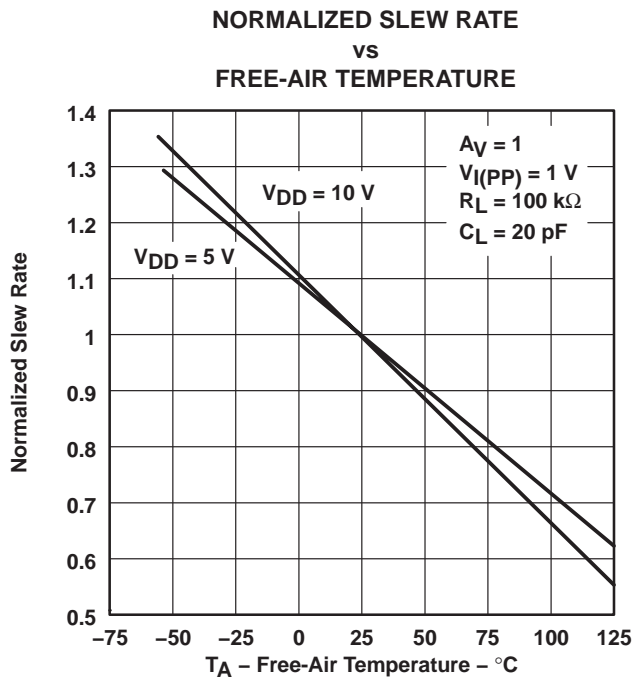


Figure 28

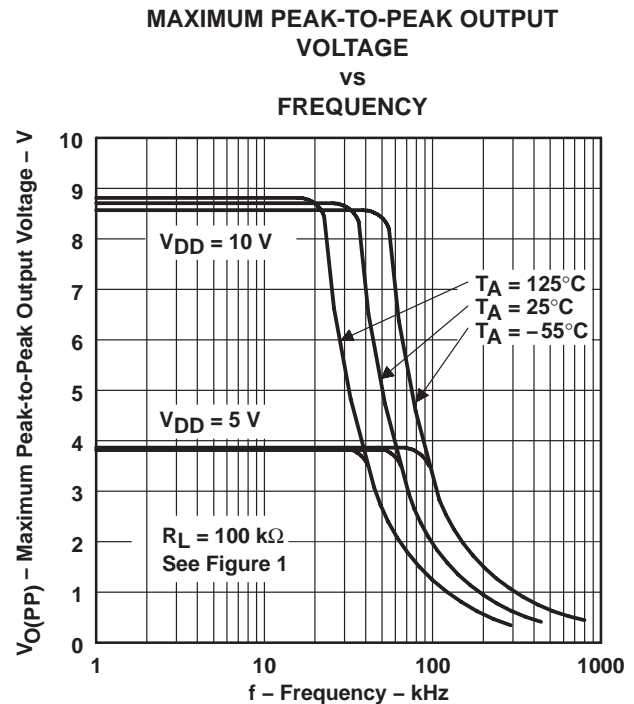


Figure 29

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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## TYPICAL CHARACTERISTICS†

UNITY-GAIN BANDWIDTH  
vs  
FREE-AIR TEMPERATURE

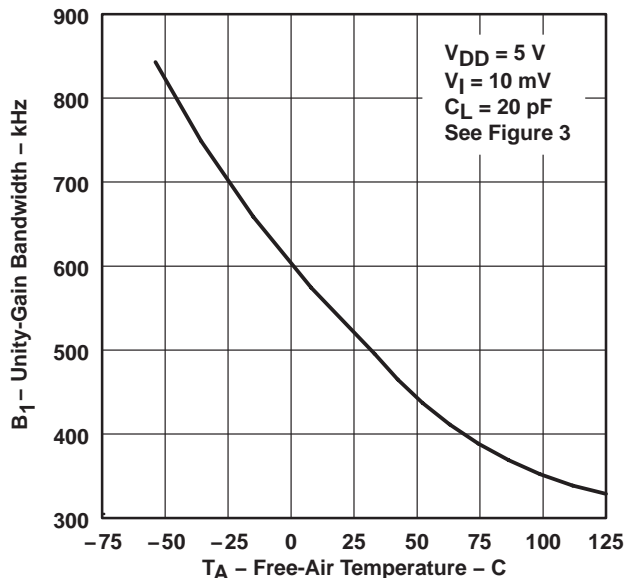


Figure 30

UNITY-GAIN BANDWIDTH  
vs  
SUPPLY VOLTAGE

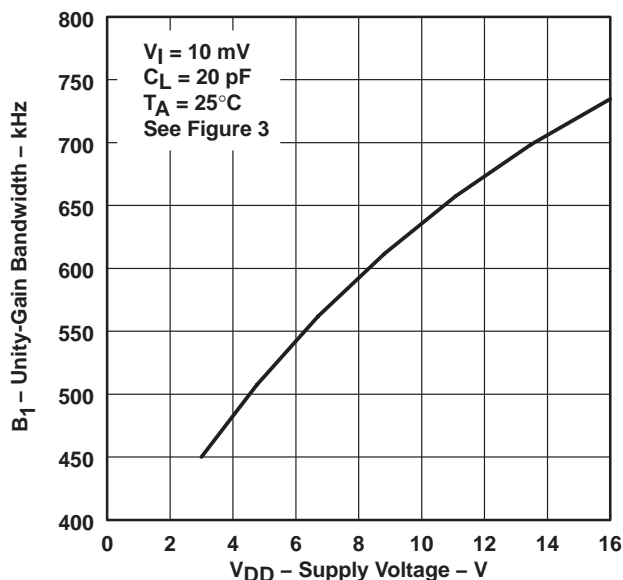


Figure 31

LARGE-SCALE DIFFERENTIAL VOLTAGE  
AMPLIFICATION AND PHASE SHIFT  
vs  
FREQUENCY

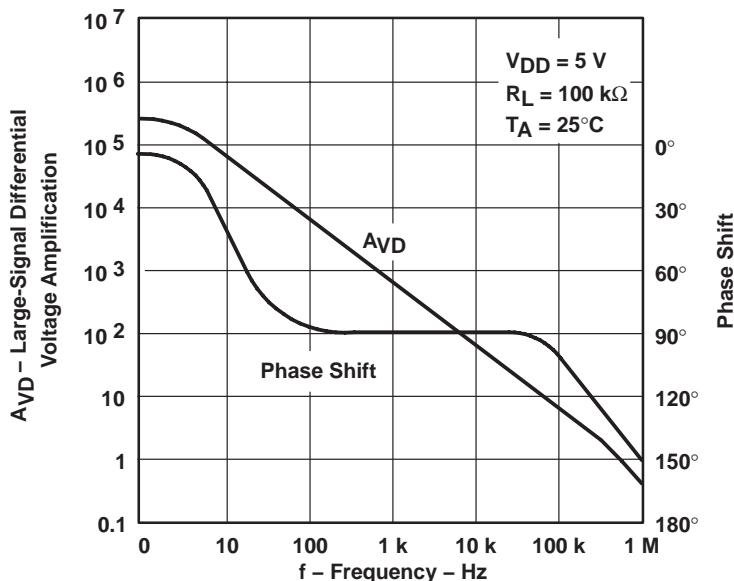


Figure 32

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.



TYPICAL CHARACTERISTICS†

LARGE-SCALE DIFFERENTIAL VOLTAGE  
 AMPLIFICATION AND PHASE SHIFT  
 vs  
 FREQUENCY



Figure 33

PHASE MARGIN  
 vs  
 SUPPLY VOLTAGE



Figure 34

PHASE MARGIN  
 vs  
 FREE-AIR TEMPERATURE



Figure 35

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS

PHASE MARGIN  
 vs  
 CAPACITIVE LOAD



Figure 36

EQUIVALENT INPUT NOISE VOLTAGE  
 vs  
 FREQUENCY



Figure 37

## APPLICATION INFORMATION

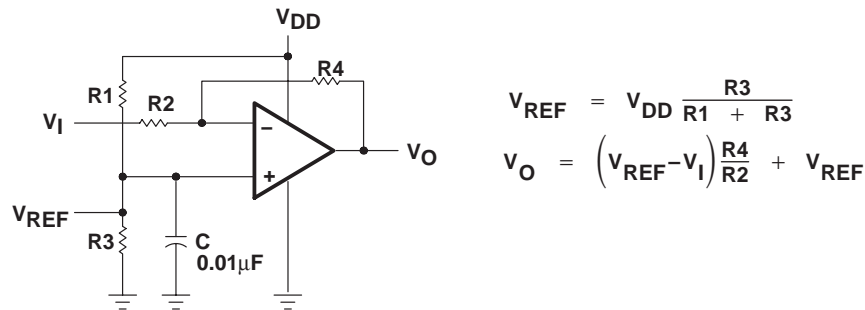
### single-supply operation

While the TLC27M2 and TLC27M7 perform well using dual power supplies (also called balanced or split supplies), the design is optimized for single-supply operation. This design includes an input common-mode voltage range that encompasses ground, as well as an output voltage range that pulls down to ground. The supply voltage range extends down to 3 V (C-suffix types), thus allowing operation with supply levels commonly available for TTL and HCMOS; however, for maximum dynamic range, 16-V single-supply operation is recommended.

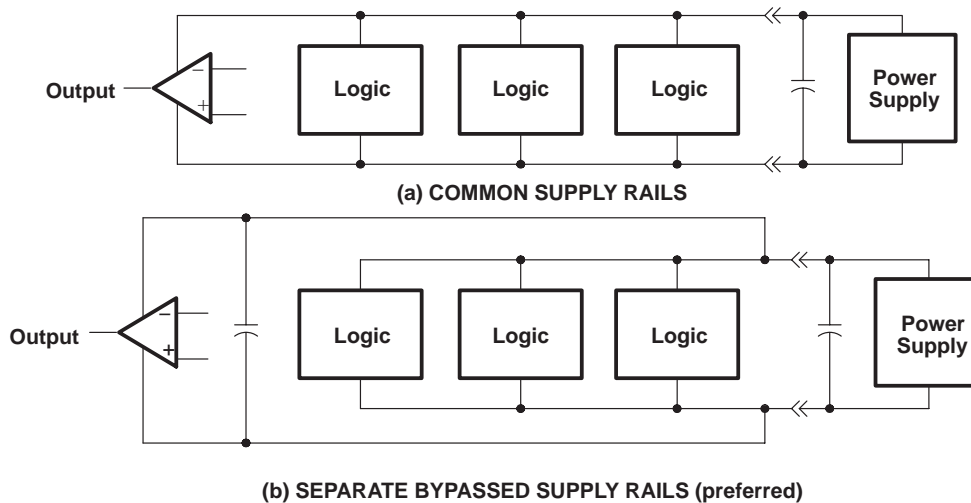
Many single-supply applications require that a voltage be applied to one input to establish a reference level that is above ground. A resistive voltage divider is usually sufficient to establish this reference level (see Figure 38). The low input bias current of the TLC27M2 and TLC27M7 permits the use of very large resistive values to implement the voltage divider, thus minimizing power consumption.

The TLC27M2 and TLC27M7 work well in conjunction with digital logic; however, when powering both linear devices and digital logic from the same power supply, the following precautions are recommended:

1. Power the linear devices from separate bypassed supply lines (see Figure 39); otherwise, the linear device supply rails can fluctuate due to voltage drops caused by high switching currents in the digital logic.
2. Use proper bypass techniques to reduce the probability of noise-induced errors. Single capacitive decoupling is often adequate; however, high-frequency applications may require RC decoupling.



**Figure 38. Inverting Amplifier With Voltage Reference**



**Figure 39. Common Versus Separate Supply Rails**

# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

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## APPLICATION INFORMATION

### input characteristics

The TLC27M2 and TLC27M7 are specified with a minimum and a maximum input voltage that, if exceeded at either input, could cause the device to malfunction. Exceeding this specified range is a common problem, especially in single-supply operation. Note that the lower range limit includes the negative rail, while the upper range limit is specified at  $V_{DD} - 1$  V at  $T_A = 25^\circ\text{C}$  and at  $V_{DD} - 1.5$  V at all other temperatures.

The use of the polysilicon-gate process and the careful input circuit design gives the TLC27M2 and TLC27M7 very good input offset voltage drift characteristics relative to conventional metal-gate processes. Offset voltage drift in CMOS devices is highly influenced by threshold voltage shifts caused by polarization of the phosphorus dopant implanted in the oxide. Placing the phosphorus dopant in a conductor (such as a polysilicon gate) alleviates the polarization problem, thus reducing threshold voltage shifts by more than an order of magnitude. The offset voltage drift with time has been calculated to be typically  $0.1 \mu\text{V}/\text{month}$ , including the first month of operation.

Because of the extremely high input impedance and resulting low bias current requirements, the TLC27M2 and TLC27M7 are well suited for low-level signal processing; however, leakage currents on printed-circuit boards and sockets can easily exceed bias current requirements and cause a degradation in device performance. It is good practice to include guard rings around inputs (similar to those of Figure 4 in the Parameter Measurement Information section). These guards should be driven from a low-impedance source at the same voltage level as the common-mode input (see Figure 40).

The inputs of any unused amplifiers should be tied to ground to avoid possible oscillation.

### noise performance

The noise specifications in operational amplifier circuits are greatly dependent on the current in the first-stage differential amplifier. The low input bias current requirements of the TLC27M2 and TLC27M7 result in a very low noise current, which is insignificant in most applications. This feature makes the devices especially favorable over bipolar devices when using values of circuit impedance greater than  $50 \text{ k}\Omega$ , since bipolar devices exhibit greater noise currents.

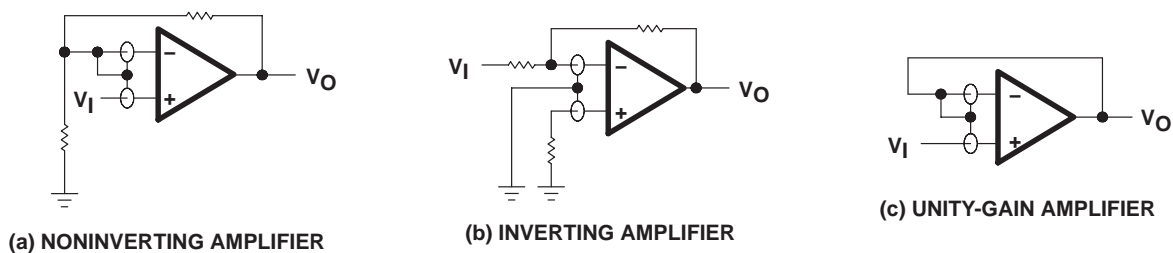


Figure 40. Guard-Ring Schemes

### output characteristics

The output stage of the TLC27M2 and TLC27M7 is designed to sink and source relatively high amounts of current (see typical characteristics). If the output is subjected to a short-circuit condition, this high current capability can cause device damage under certain conditions. Output current capability increases with supply voltage.

All operating characteristics of the TLC27M2 and TLC27M7 were measured using a  $20\text{-pF}$  load. The devices drive higher capacitive loads; however, as output load capacitance increases, the resulting response pole occurs at lower frequencies, thereby causing ringing, peaking, or even oscillation (see Figure 41). In many cases, adding a small amount of resistance in series with the load capacitance alleviates the problem.

APPLICATION INFORMATION



Figure 41. Effect of Capacitive Loads and Test Circuit

output characteristics (continued)

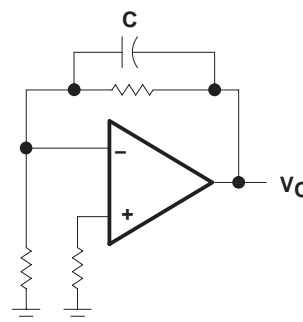
Although the TLC27M2 and TLC27M7 possess excellent high-level output voltage and current capability, methods for boosting this capability are available, if needed. The simplest method involves the use of a pullup resistor ( $R_P$ ) connected from the output to the positive supply rail (see Figure 42). There are two disadvantages to the use of this circuit. First, the NMOS pulldown transistor N4 (see equivalent schematic) must sink a comparatively large amount of current. In this circuit, N4 behaves like a linear resistor with an on-resistance between approximately  $60 \Omega$  and  $180 \Omega$ , depending on how hard the operational amplifier input is driven. With very low values of  $R_P$ , a voltage offset from 0 V at the output occurs. Second, pullup resistor  $R_P$  acts as a drain load to N4 and the gain of the operational amplifier is reduced at output voltage levels where N5 is not supplying the output current.

**APPLICATION INFORMATION**

**output characteristics (continued)**



**Figure 42. Resistive Pullup to Increase VOH**



**Figure 43. Compensation for Input Capacitance**

**feedback**

Operational amplifier circuits nearly always employ feedback, and since feedback is the first prerequisite for oscillation, some caution is appropriate. Most oscillation problems result from driving capacitive loads (discussed previously) and ignoring stray input capacitance. A small-value capacitor connected in parallel with the feedback resistor is an effective remedy (see Figure 43). The value of this capacitor is optimized empirically.

**electrostatic-discharge protection**

The TLC27M2 and TLC27M7 incorporate an internal electrostatic-discharge (ESD) protection circuit that prevents functional failures at voltages up to 2000 V as tested under MIL-STD-883C, Method 3015.2. Care should be exercised, however, when handling these devices as exposure to ESD may result in the degradation of the device parametric performance. The protection circuit also causes the input bias currents to be temperature dependent and have the characteristics of a reverse-biased diode.

**latch-up**

Because CMOS devices are susceptible to latch-up due to their inherent parasitic thyristors, the TLC27M2 and TLC27M7 inputs and outputs were designed to withstand –100-mA surge currents without sustaining latch-up; however, techniques should be used to reduce the chance of latch-up whenever possible. Internal protection diodes should not, by design, be forward biased. Applied input and output voltage should not exceed the supply voltage by more than 300 mV. Care should be exercised when using capacitive coupling on pulse generators. Supply transients should be shunted by the use of decoupling capacitors (0.1  $\mu$ F typical) located across the supply rails as close to the device as possible.

The current path established if latch-up occurs is usually between the positive supply rail and ground and can be triggered by surges on the supply lines and/or voltages on either the output or inputs that exceed the supply voltage. Once latch-up occurs, the current flow is limited only by the impedance of the power supply and the forward resistance of the parasitic thyristor and usually results in the destruction of the device. The chance of latch-up occurring increases with increasing temperature and supply voltages.

APPLICATION INFORMATION



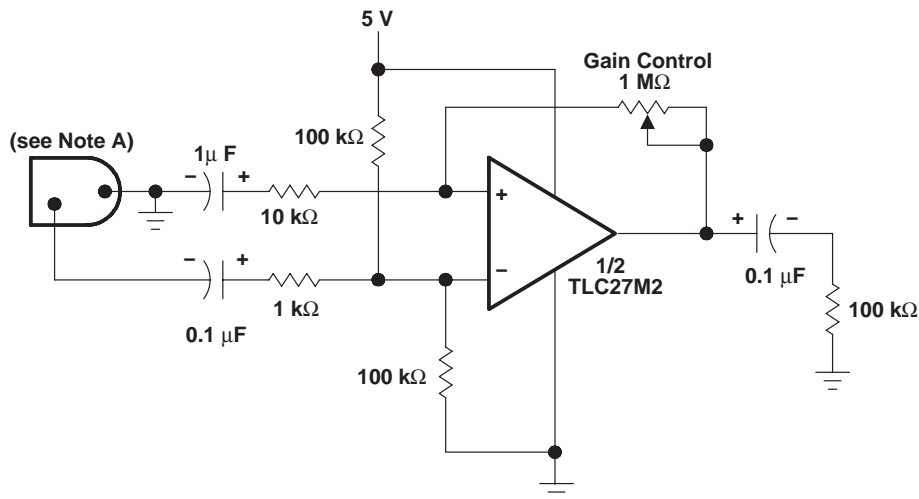
NOTES:  $V_{O(PP)} \approx 2 V$   
 $f_O = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$

Figure 44. Wien Oscillator



NOTES:  $V_I = 0 V$  to  $3 V$   
 $I_S = \frac{V_I}{R}$

Figure 45. Precision Low-Current Sink



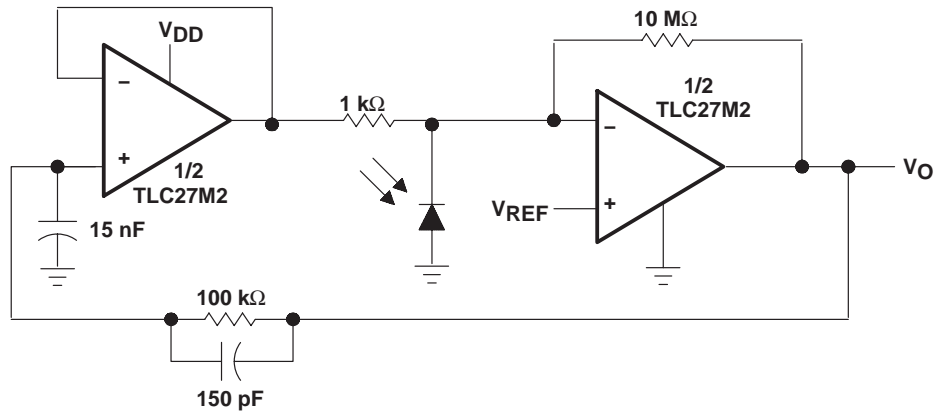
NOTE A: Low to medium impedance dynamic mike

Figure 46. Microphone Preamplifier

# TLC27M2, TLC27M2A, TLC27M2B, TLC27M7 LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

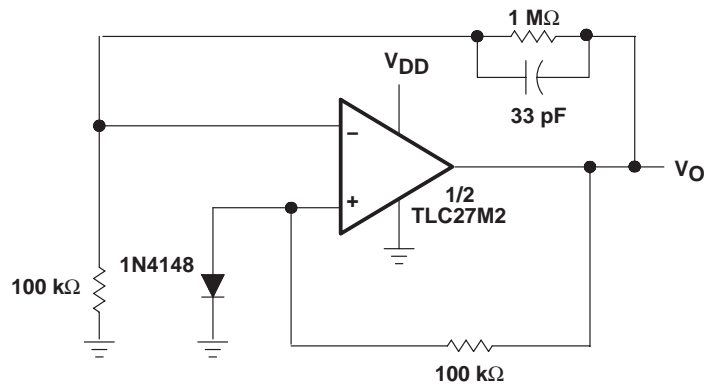
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## APPLICATION INFORMATION



NOTES:  $V_{DD} = 4\text{ V to }15\text{ V}$   
 $V_{ref} = 0\text{ V to }V_{DD} - 2\text{ V}$

Figure 47. Photo-Diode Amplifier With Ambient Light Rejection



NOTES:  $V_{DD} = 8\text{ V to }16\text{ V}$   
 $V_O = 5\text{ V, }10\text{ mA}$

Figure 48. 5-V Low-Power Voltage Regulator

APPLICATION INFORMATION

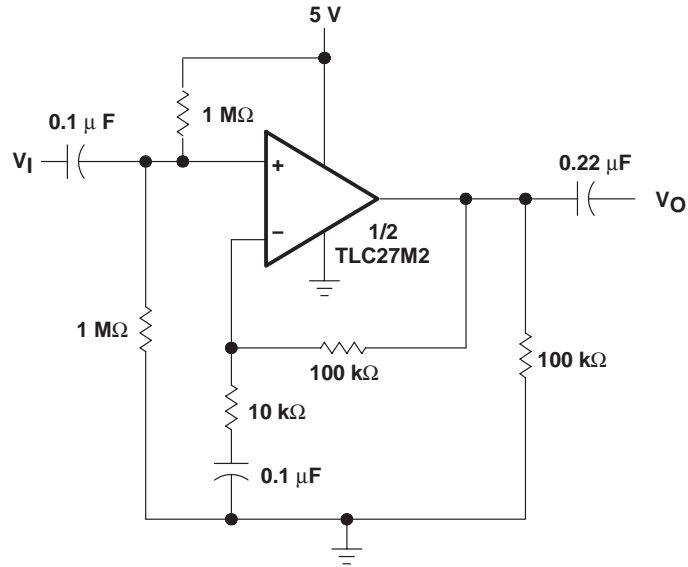


Figure 49. Single-Rail AC Amplifiers

**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
TLC27M2ACDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	27M2AC	<a href="#">Samples</a>
TLC27M2ACP	ACTIVE	PDIP	P	8	50	RoHS & Green	NIPDAU	N / A for Pkg Type	0 to 70	TLC27M2AC	<a href="#">Samples</a>
TLC27M2ACPE4	ACTIVE	PDIP	P	8	50	RoHS & Green	NIPDAU	N / A for Pkg Type	0 to 70	TLC27M2AC	<a href="#">Samples</a>
TLC27M2AIDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	27M2AI	<a href="#">Samples</a>
TLC27M2AIP	ACTIVE	PDIP	P	8	50	RoHS & Green	NIPDAU	N / A for Pkg Type	-40 to 85	TLC27M2AI	<a href="#">Samples</a>
TLC27M2BCDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	27M2BC	<a href="#">Samples</a>
TLC27M2BCP	ACTIVE	PDIP	P	8	50	RoHS & Green	NIPDAU	N / A for Pkg Type	0 to 70	TLC27M2BC	<a href="#">Samples</a>
TLC27M2BIDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	27M2BI	<a href="#">Samples</a>
TLC27M2BIP	ACTIVE	PDIP	P	8	50	RoHS & Green	NIPDAU	N / A for Pkg Type	-40 to 85	TLC27M2BI	<a href="#">Samples</a>
TLC27M2CDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	27M2C	<a href="#">Samples</a>
TLC27M2CP	ACTIVE	PDIP	P	8	50	RoHS & Green	NIPDAU	N / A for Pkg Type	0 to 70	TLC27M2CP	<a href="#">Samples</a>
TLC27M2CPS	ACTIVE	SO	PS	8	80	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	P27M2	<a href="#">Samples</a>
TLC27M2CPSR	ACTIVE	SO	PS	8	2000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	P27M2	<a href="#">Samples</a>
TLC27M2CPWR	ACTIVE	TSSOP	PW	8	2000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	P27M2	<a href="#">Samples</a>
TLC27M2IDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	27M2I	<a href="#">Samples</a>
TLC27M2IP	ACTIVE	PDIP	P	8	50	RoHS & Green	NIPDAU	N / A for Pkg Type	-40 to 85	TLC27M2IP	<a href="#">Samples</a>
TLC27M2IPWR	ACTIVE	TSSOP	PW	8	2000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	P27M2I	<a href="#">Samples</a>
TLC27M2IPWRG4	ACTIVE	TSSOP	PW	8	2000	TBD	Call TI	Call TI	0 to 70		<a href="#">Samples</a>
TLC27M2MD	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-55 to 125	27M2M	<a href="#">Samples</a>
TLC27M2MDG4	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-55 to 125	27M2M	<a href="#">Samples</a>

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
TLC27M7CDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	27M7C	<a href="#">Samples</a>
TLC27M7CP	ACTIVE	PDIP	P	8	50	RoHS & Green	NIPDAU	N / A for Pkg Type	0 to 70	TLC27M7CP	<a href="#">Samples</a>
TLC27M7CPS	ACTIVE	SO	PS	8	80	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	P27M7	<a href="#">Samples</a>
TLC27M7CPSR	ACTIVE	SO	PS	8	2000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	P27M7	<a href="#">Samples</a>
TLC27M7IDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 85	27M7I	<a href="#">Samples</a>
TLC27M7IP	ACTIVE	PDIP	P	8	50	RoHS & Green	NIPDAU	N / A for Pkg Type	-40 to 85	TLC27M7IP	<a href="#">Samples</a>

(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.

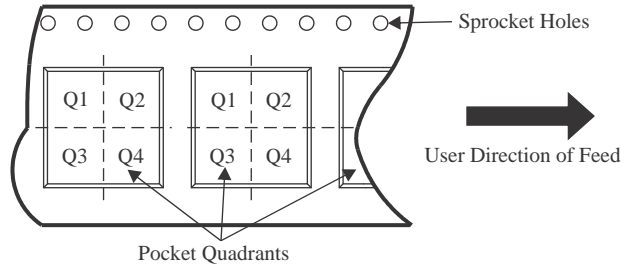
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(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
TLC27M2ACDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC27M2AIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC27M2BCDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC27M2BIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC27M2CDDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC27M2CPSR	SO	PS	8	2000	330.0	16.4	8.35	6.6	2.5	12.0	16.0	Q1
TLC27M2CPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
TLC27M2CPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
TLC27M2IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC27M2IPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
TLC27M2IPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
TLC27M7CDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC27M7CPSR	SO	PS	8	2000	330.0	16.4	8.35	6.6	2.5	12.0	16.0	Q1
TLC27M7IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	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)
TLC27M2ACDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC27M2AIDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC27M2BCDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC27M2BIDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC27M2CDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC27M2CPSR	SO	PS	8	2000	356.0	356.0	35.0
TLC27M2CPWR	TSSOP	PW	8	2000	356.0	356.0	35.0
TLC27M2CPWR	TSSOP	PW	8	2000	356.0	356.0	35.0
TLC27M2IDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC27M2IPWR	TSSOP	PW	8	2000	356.0	356.0	35.0
TLC27M2IPWR	TSSOP	PW	8	2000	356.0	356.0	35.0
TLC27M7CDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC27M7CPSR	SO	PS	8	2000	356.0	356.0	35.0
TLC27M7IDR	SOIC	D	8	2500	340.5	338.1	20.6

**TUBE**


\*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	L (mm)	W (mm)	T (μm)	B (mm)
TLC27M2ACP	P	PDIP	8	50	506	13.97	11230	4.32
TLC27M2ACPE4	P	PDIP	8	50	506	13.97	11230	4.32
TLC27M2AIP	P	PDIP	8	50	506	13.97	11230	4.32
TLC27M2BCP	P	PDIP	8	50	506	13.97	11230	4.32
TLC27M2BIP	P	PDIP	8	50	506	13.97	11230	4.32
TLC27M2CP	P	PDIP	8	50	506	13.97	11230	4.32
TLC27M2CPS	PS	SOP	8	80	530	10.5	4000	4.1
TLC27M2IP	P	PDIP	8	50	506	13.97	11230	4.32
TLC27M2MD	D	SOIC	8	75	505.46	6.76	3810	4
TLC27M2MDG4	D	SOIC	8	75	505.46	6.76	3810	4
TLC27M7CP	P	PDIP	8	50	506	13.97	11230	4.32
TLC27M7CPS	PS	SOP	8	80	530	10.5	4000	4.1
TLC27M7IP	P	PDIP	8	50	506	13.97	11230	4.32



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.

## MECHANICAL DATA

PS (R-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Body dimensions do not include mold flash or protrusion, not to exceed 0,15.

PS (R-PDSO-G8)

PLASTIC SMALL OUTLINE



- NOTES:
- All linear dimensions are in millimeters.
  - This drawing is subject to change without notice.
  - Publication IPC-7351 is recommended for alternate designs.
  - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
  - Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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.

PW0008A



**PACKAGE OUTLINE**  
**TSSOP - 1.2 mm max height**

SMALL OUTLINE PACKAGE



4221848/A 02/2015

NOTES:

- All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
- This drawing is subject to change without notice.
- 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.
- This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
- Reference JEDEC registration MO-153, variation AA.

# EXAMPLE BOARD LAYOUT

PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE  
SCALE:10X



SOLDER MASK DETAILS  
NOT TO SCALE

4221848/A 02/2015

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

PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL  
SCALE:10X

4221848/A 02/2015

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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