

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

SLOS051E – OCTOBER 1987 – REVISED AUGUST 2008

- **Trimmed Offset Voltage:**
TLC27M7 . . . 500 μV 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)

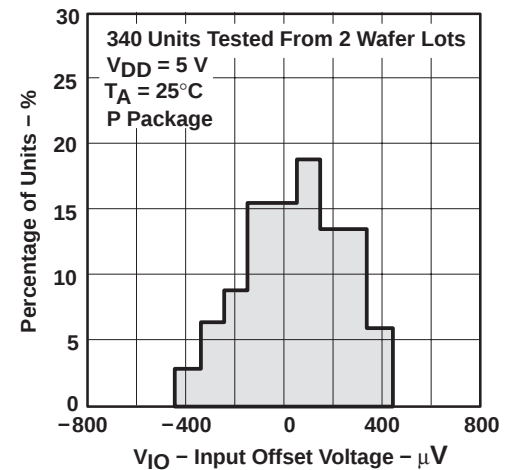


FK PACKAGE
(TOP VIEW)



NC – No internal connection

DISTRIBUTION OF TLC27M7
INPUT OFFSET VOLTAGE



AVAILABLE OPTIONS

T_A	V_{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 μV	TLC27M7CD	—	—	TLC27M7CP	—
	2 mV	TLC27M2BCD	—	—	TLC27M2BCP	—
	5 mV	TLC27M2ACD	—	—	TLC27M2ACP	—
	10 mV	TLC27M2CD	—	—	TLC27M2CP	TLC27M2CPW
–40°C to 85°C	500 μV	TLC27M7ID	—	—	TLC27M7IP	—
	2 mV	TLC27M2BID	—	—	TLC27M2BIP	—
	5 mV	TLC27M2AID	—	—	TLC27M2AIP	—
	10 mV	TLC27M2ID	—	—	TLC27M2IP	TLC27M2IPW
–55°C to 125°C	500 μV	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.

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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 μ 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.

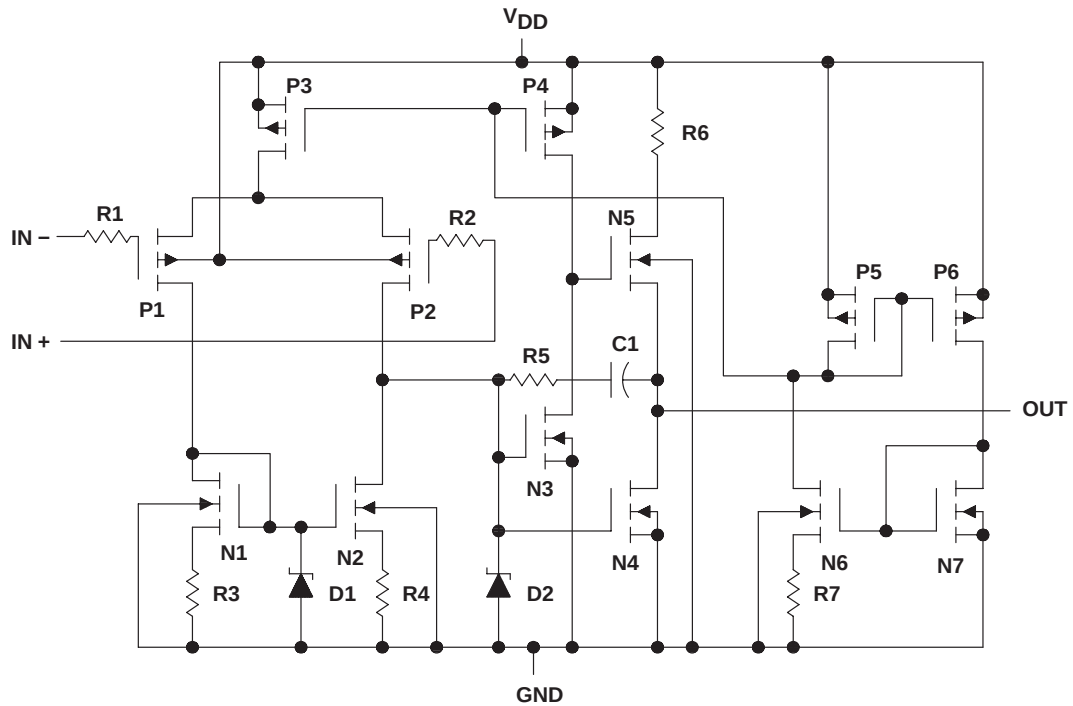
The TLC27M2 and TLC27M7 incorporate internal ESD-protection circuits that prevent functional failures at voltages up to 2000 V as tested under MIL-STD-883C, Method 3015.2; however, care should be exercised in handling these devices as exposure to ESD may result in the degradation of the device parametric 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)	$-0.3 \text{ V to } V_{DD}$
Input current, I_I	$\pm 5 \text{ mA}$
Output current, I_O (each output)	$\pm 30 \text{ mA}$
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}	$V_{DD} = 5 \text{ V}$	-0.2	3.5	-0.2	3.5	0	3.5	V
	$V_{DD} = 10 \text{ V}$	-0.2	8.5	-0.2	8.5	0	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 V, R _S = 50 Ω,	V _{IC} = 0, R _I = 100 kΩ	25°C	1.1	10	mV
					Full range		12	
		TLC27M2AC	V _O = 1.4 V, R _S = 50 Ω,	V _{IC} = 0, R _I = 100 kΩ	25°C	0.9	5	
					Full range		6.5	
		TLC27M2BC	V _O = 1.4 V, R _S = 50 Ω,	V _{IC} = 0, R _I = 100 kΩ	25°C	220	2000	μV
					Full range		3000	
		TLC27M7C	V _O = 1.4 V, R _S = 50 Ω,	V _{IC} = 0, R _I = 100 kΩ	25°C	185	500	
					Full range		1500	
αV _{IO}	Average temperature coefficient of input offset voltage			25°C to 70°C	1.7		μV/°C	
I _{IO}	Input offset current (see Note 4)	V _O = 2.5 V,	V _{IC} = 2.5 V	25°C	0.1	60	pA	
				70°C	7	300		
I _{IB}	Input bias current (see Note 4)	V _O = 2.5 V,	V _{IC} = 2.5 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 mV,	R _L = 100 kΩ	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 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 V to 2 V, R _L = 100 kΩ		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 (ΔV _{DD} /ΔV _{IO})	V _{DD} = 5 V to 10 V, V _O = 1.4 V		25°C	70	93	dB	
				0°C	60	92		
				70°C	60	94		
I _{DD}	Supply current (two amplifiers)	V _O = 2.5 V, No load	V _{IC} = 2.5 V,	25°C	210	560	μA	
				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.



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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 V, R _S = 50 Ω, V _{IC} = 0, R _L = 100 kΩ	25°C	1.1	10	mV	
				Full range		12		
		TLC27M2AC	V _O = 1.4 V, R _S = 50 Ω, V _{IC} = 0, R _L = 100 kΩ	25°C	0.9	5		
				Full range		6.5		
		TLC27M2BC	V _O = 1.4 V, R _S = 50 Ω, V _{IC} = 0, R _L = 100 kΩ	25°C	224	2000	μV	
				Full range		3000		
		TLC27M7C	V _O = 1.4 V, R _S = 50 Ω, V _{IC} = 0, R _L = 100 kΩ	25°C	190	800		
				Full range		1900		
αVIO	Average temperature coefficient of input offset voltage			25°C to 70°C	2.1		μV/°C	
I _{IO}	Input offset current (see Note 4)	V _O = 5 V,	V _{IC} = 5 V	25°C	0.1	60	pA	
				70°C	7	300		
I _{IB}	Input bias current (see Note 4)	V _O = 5 V,	V _{IC} = 5 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 mV, R _L = 100 kΩ		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 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 V to 6 V, R _L = 100 kΩ		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 (ΔV _{DD} /ΔV _{IO})	V _{DD} = 5 V to 10 V, V _O = 1.4 V		25°C	70	93	dB	
				0°C	60	92		
				70°C	60	94		
I _{DD}	Supply current (two amplifiers)	V _O = 5 V, No load V _{IC} = 5 V,		25°C	285	600	μA	
				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		$T_A^\dagger$	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		220	2000	μV
				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	
				Full range			2000	
α_{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	$V_{IC} = V_{ICRmin}$		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	μA
				-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 V, R _S = 50 Ω,	V _{IC} = 0, R _L = 100 kΩ	25°C	1.1	10	mV
					Full range		13	
		TLC27M2AI	V _O = 1.4 V, R _S = 50 Ω,	V _{IC} = 0, R _L = 100 kΩ	25°C	0.9	5	
					Full range		7	
	TLC27M2BI	V _O = 1.4 V, R _S = 50 Ω,	V _{IC} = 0, R _L = 100 kΩ	25°C	224	2000	μV	
				Full range		3500		
		TLC27M7I	V _O = 1.4 V, R _S = 50 Ω,	V _{IC} = 0, R _L = 100 kΩ	25°C	190		800
					Full range			2900
αV _{IO}	Average temperature coefficient of input offset voltage			25°C to 85°C	2.1		μV/°C	
I _{IO}	Input offset current (see Note 4)	V _O = 5 V,	V _{IC} = 5 V	25°C	0.1	60	pA	
				85°C	26	1000		
I _{IB}	Input bias current (see Note 4)	V _O = 5 V,	V _{IC} = 5 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 mV,	R _L = 100 kΩ	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 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 V to 6 V,	R _L = 100 kΩ	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 (ΔV _{DD} /ΔV _{IO})	V _{DD} = 5 V to 10 V,	V _O = 1.4 V	25°C	70	93	dB	
				-40°C	60	91		
				85°C	60	94		
I _{DD}	Supply current	V _O = 5 V, No load	V _{IC} = 5 V,	25°C	285	600	μA	
				-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.



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

PARAMETER		TEST CONDITIONS		$T_A^\dagger$	TLC27M2M TLC27M7M			UNIT
					MIN	TYP	MAX	
V_{IO}	Input offset voltage	TLC27M2M	$V_O = 1.4\text{ V}$, $R_S = 50\ \Omega$,	$V_{IC} = 0$, $R_L = 100\text{ k}\Omega$	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	185	500	
					Full range		3750	
α_{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	μA
					-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.



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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	TLC27M2M	$V_O = 1.4\text{ V}$, $R_S = 50\ \Omega$, $V_{IC} = 0$, $R_L = 100\text{ k}\Omega$	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	
α_{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		μA
			-55°C	490	1000		
			125°C	180	480		

† 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.



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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/ μ 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	$R_S = 20\text{ }\Omega$	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
			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	
ϕ_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°	
			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/ μ 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	$R_S = 20\text{ }\Omega$	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
			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	
ϕ_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°	
			0°C	44°	
			70°C	42°	



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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/ μ 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	$R_S = 20\text{ }\Omega$	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	
ϕ_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/ μ 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	$R_S = 20\text{ }\Omega$	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	
ϕ_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°	



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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/ μ 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	$R_S = 20\text{ }\Omega$, 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	25°C		55		kHz
		-55°C		80		
		125°C		40		
B_1 Unity-gain bandwidth	$V_I = 10\text{ mV}$, See Figure 3	25°C		525		kHz
		-55°C		850		
		125°C		330		
ϕ_m Phase margin	$V_I = 10\text{ mV}$, $C_L = 20\text{ pF}$, 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/ μ 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	$R_S = 20\text{ }\Omega$, 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	25°C		35		kHz
		-55°C		50		
		125°C		20		
B_1 Unity gain bandwidth	$V_I = 10\text{ mV}$, See Figure 3	25°C		635		kHz
		-55°C		960		
		125°C		440		
ϕ_m Phase margin	$V_I = 10\text{ mV}$, $C_L = 20\text{ pF}$, 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.

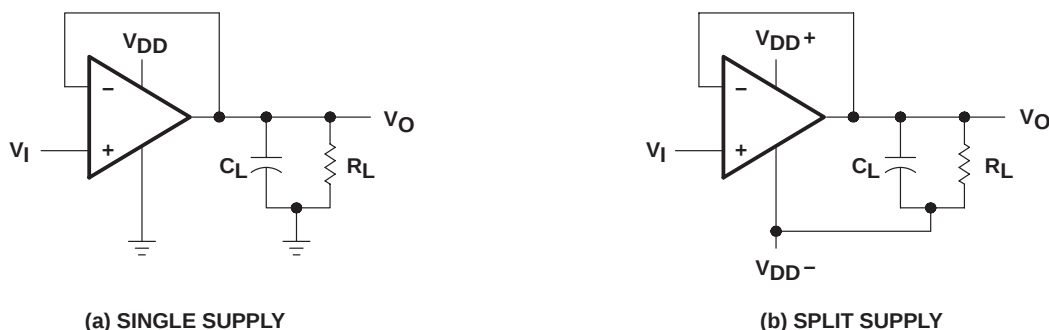


Figure 1. Unity-Gain Amplifier



Figure 2. Noise-Test Circuit

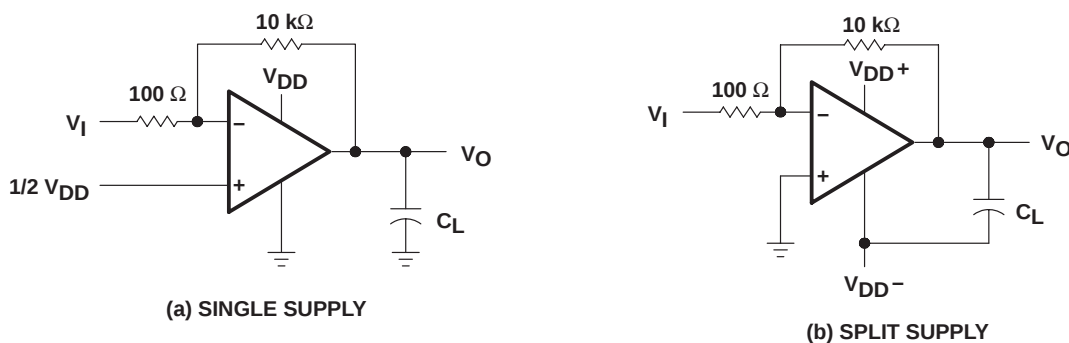


Figure 3. Gain-of-100 Inverting Amplifier

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.

TYPICAL CHARACTERISTICS

Table of Graphs

			FIGURE
V_{IO}	Input offset voltage	Distribution	6, 7
α_{VIO}	Temperature coefficient	Distribution	8, 9
V_{OH}	High-level output voltage	vs High-level output current vs Supply voltage vs Free-air temperature	10, 11 12 13
V_{OL}	Low-level output voltage	vs Common-mode input voltage vs Differential input voltage vs Free-air temperature vs Low-level output current	14, 15 16 17 18, 19
A_{VD}	Differential voltage amplification	vs Supply voltage vs Free-air temperature vs Frequency	20 21 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 vs Free-air temperature	24 25
SR	Slew rate	vs Supply voltage vs Free-air temperature	26 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 vs Supply voltage	30 31
ϕ_m	Phase margin	vs Supply voltage vs Free-air temperature vs Capacitive loads	34 35 36
V_n	Equivalent input noise voltage	vs Frequency	37
ϕ	Phase shift	vs Frequency	32, 33

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TYPICAL CHARACTERISTICS

DISTRIBUTION OF TLC27M2
INPUT OFFSET VOLTAGE

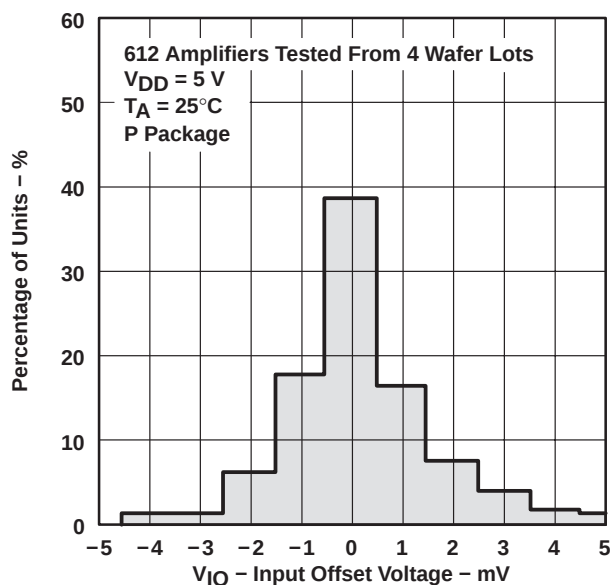


Figure 6

DISTRIBUTION OF TLC27M2
INPUT OFFSET VOLTAGE



Figure 7

DISTRIBUTION OF TLC27M2 AND TLC27M7
INPUT OFFSET VOLTAGE
TEMPERATURE COEFFICIENT

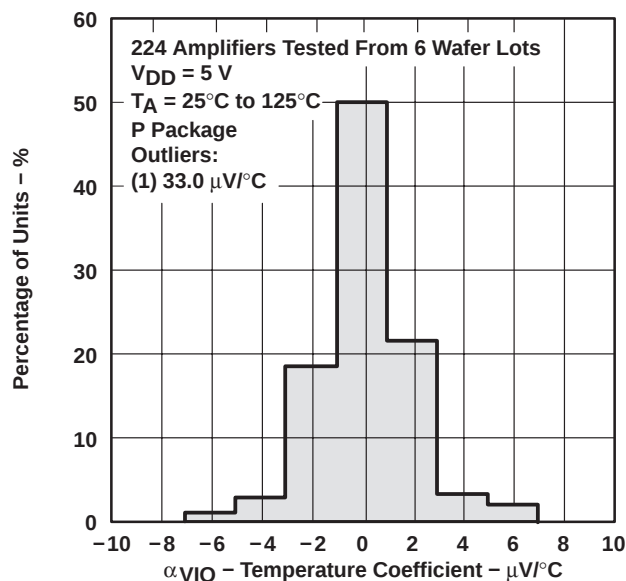


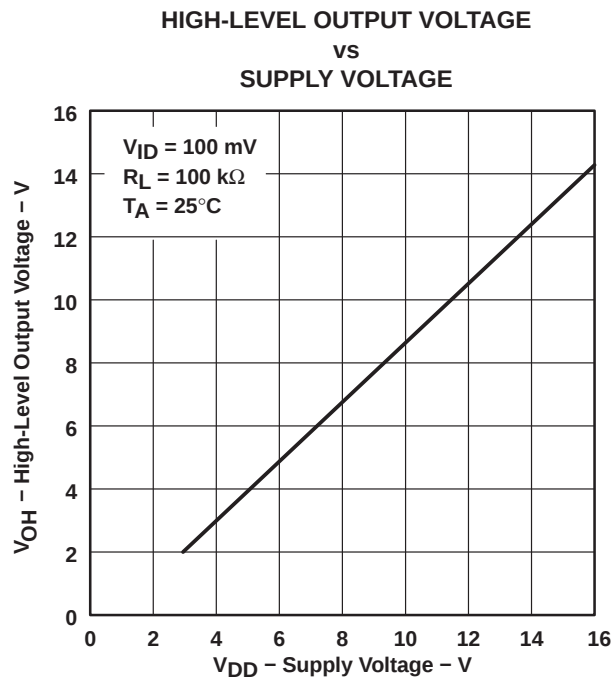
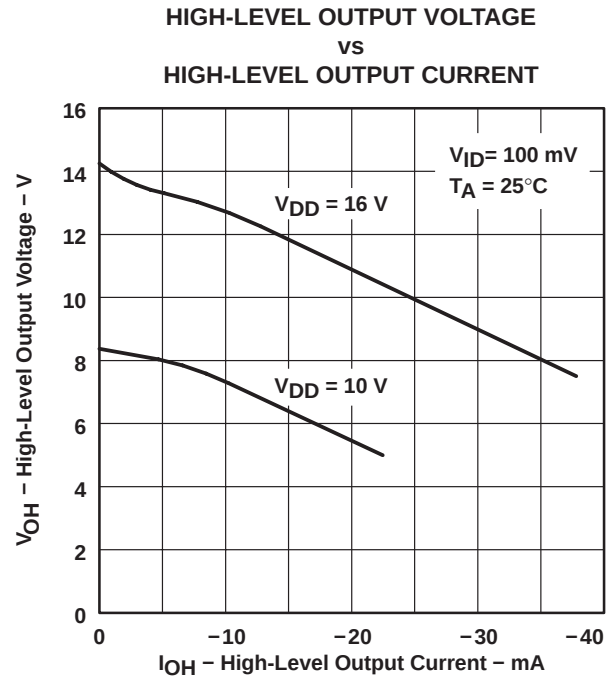
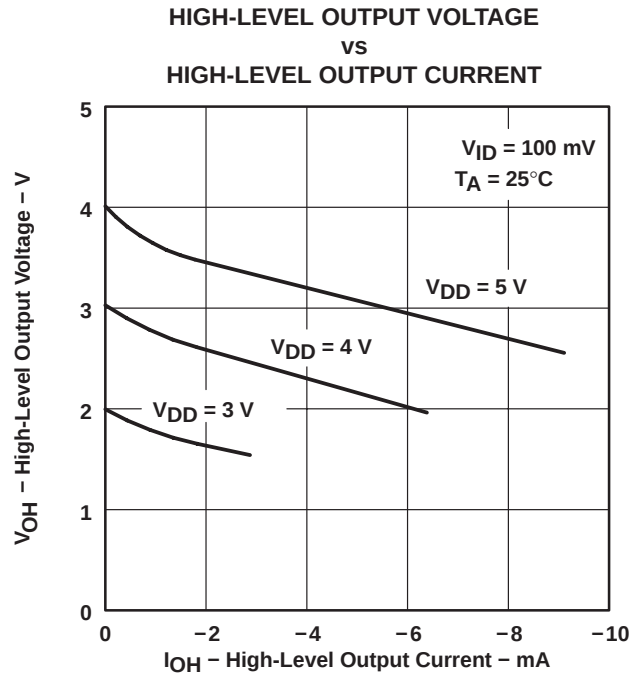
Figure 8

DISTRIBUTION OF TLC27M2 AND TLC27M7
INPUT OFFSET VOLTAGE
TEMPERATURE COEFFICIENT



Figure 9

TYPICAL CHARACTERISTICS†



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

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TYPICAL CHARACTERISTICS†



Figure 14

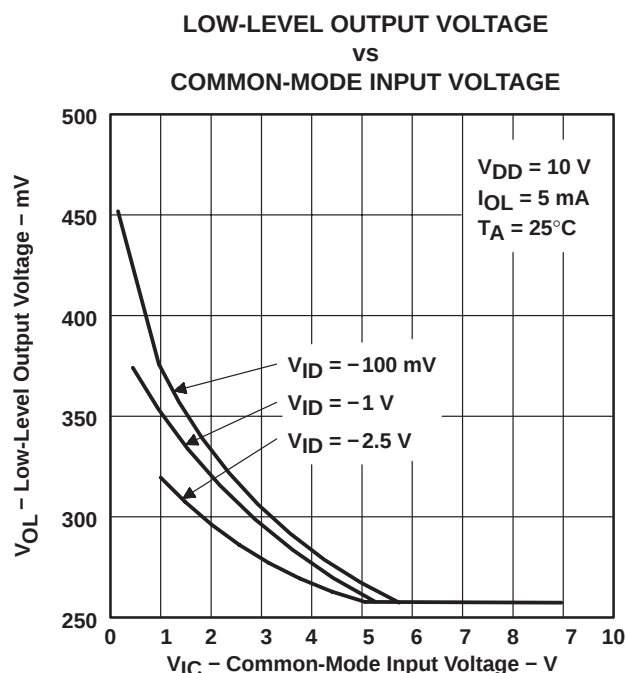


Figure 15

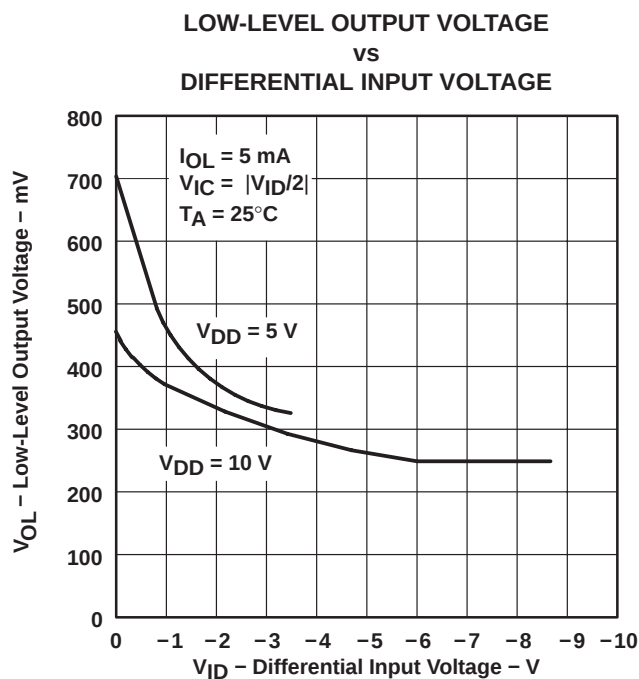


Figure 16



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†

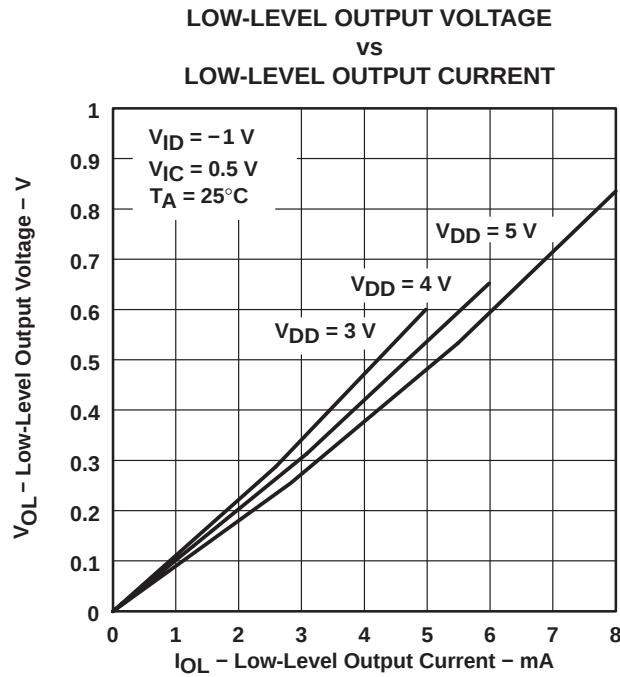


Figure 18

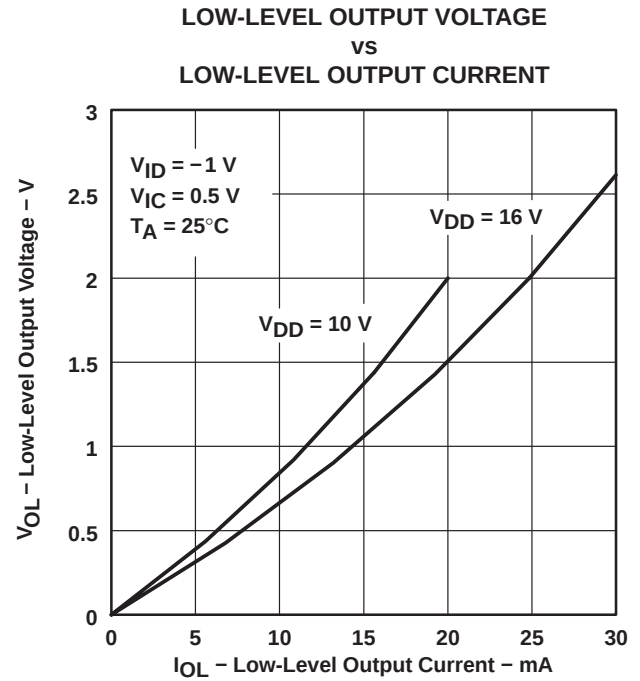


Figure 19



Figure 20

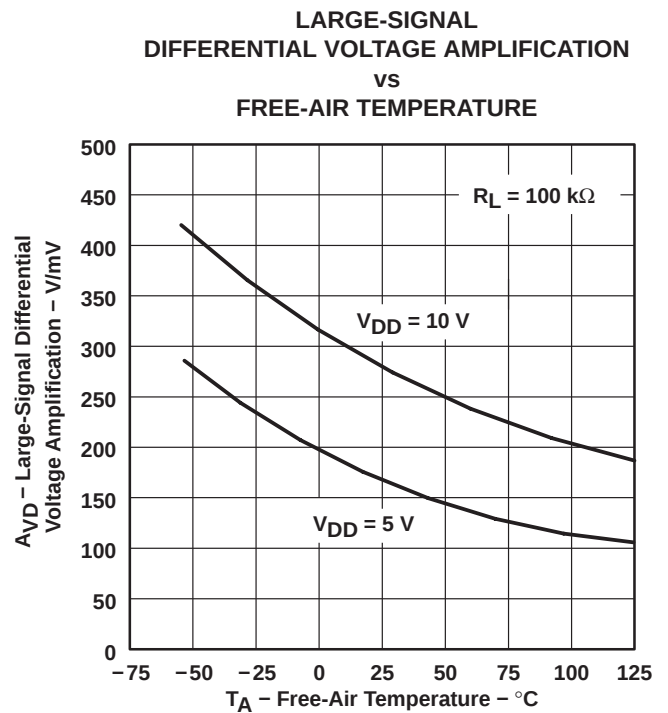


Figure 21

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

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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

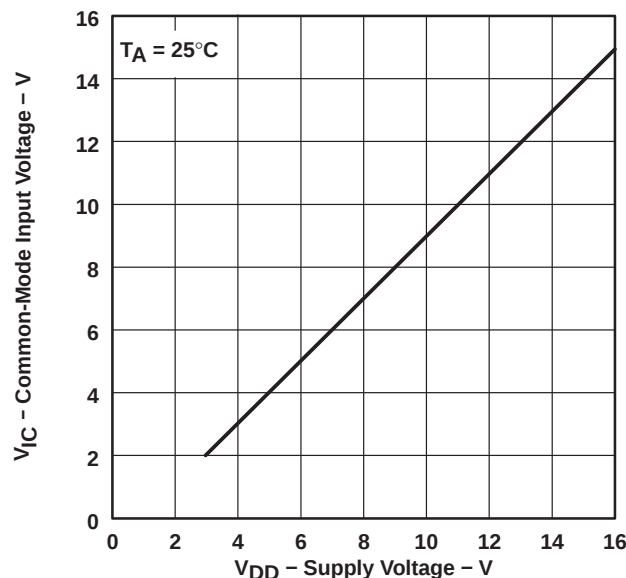


Figure 23

SUPPLY CURRENT
vs
SUPPLY VOLTAGE



Figure 24

SUPPLY CURRENT
vs
FREE-AIR TEMPERATURE

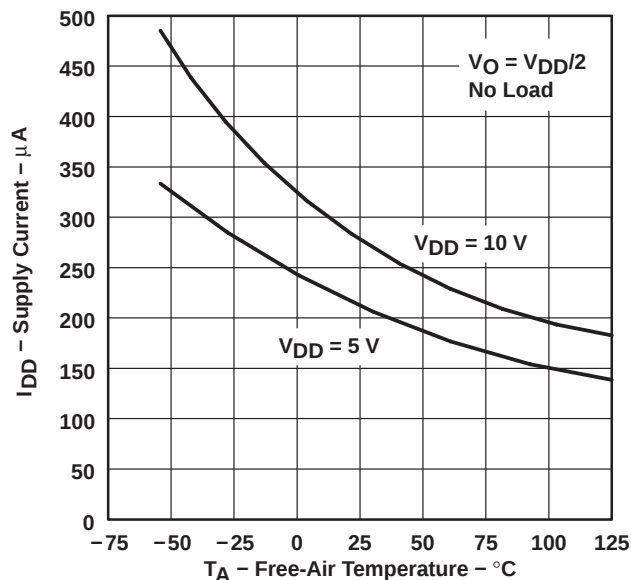


Figure 25

† 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.

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TYPICAL CHARACTERISTICS†



Figure 30

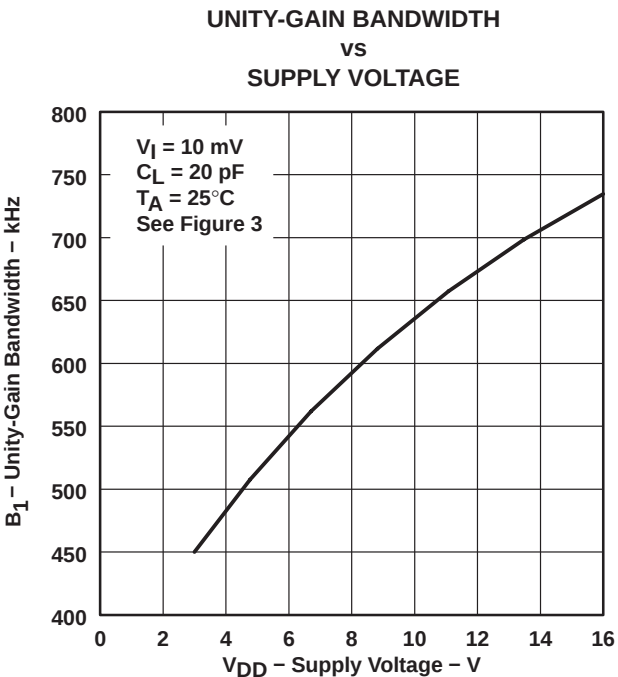


Figure 31



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

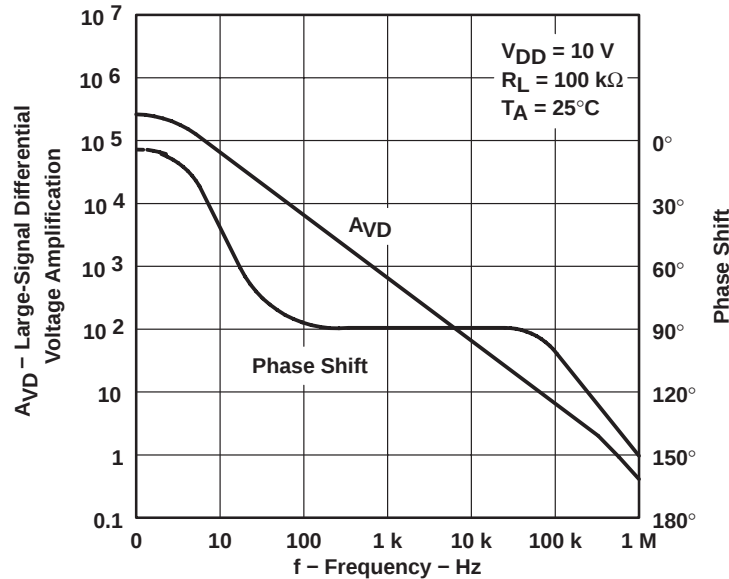


Figure 33

PHASE MARGIN vs SUPPLY VOLTAGE



Figure 34

PHASE MARGIN vs FREE-AIR TEMPERATURE

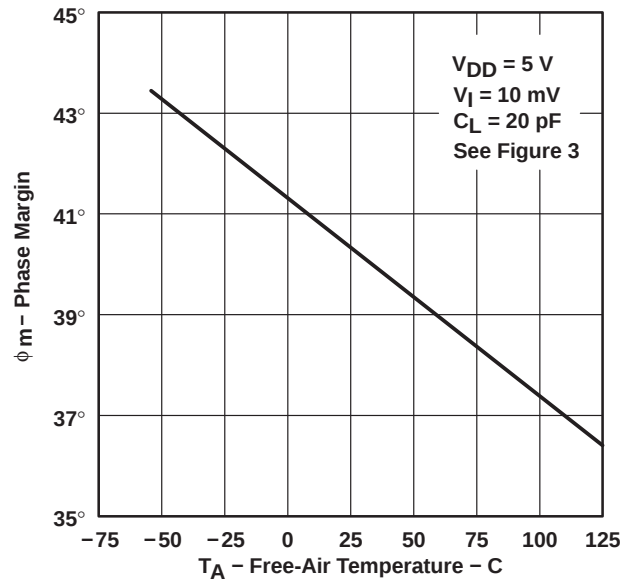


Figure 35

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

TYPICAL CHARACTERISTICS

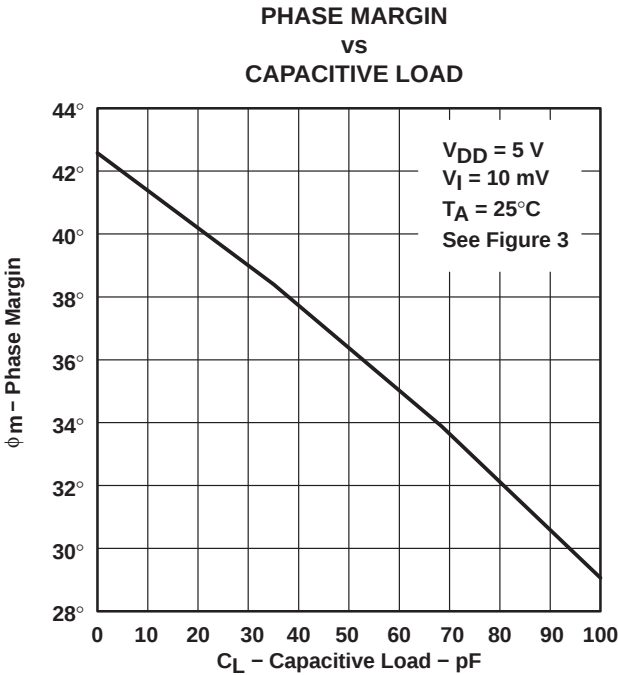


Figure 36

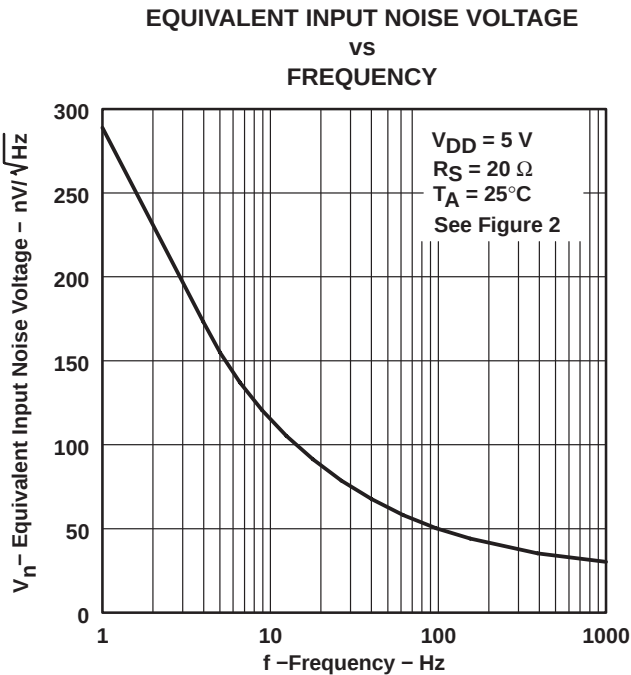


Figure 37

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.

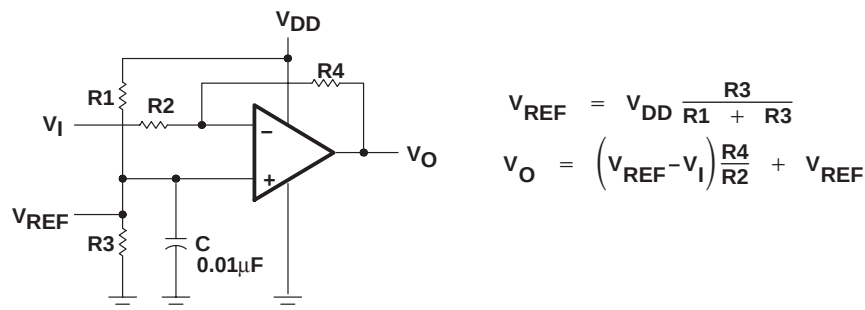


Figure 38. Inverting Amplifier With Voltage Reference



Figure 39. Common Versus Separate Supply Rails

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 $V_{DD} - 1\text{ V}$ at $T_A = 25^\circ\text{C}$ and at $V_{DD} - 1.5\text{ V}$ 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 $0.1\text{ }\mu\text{V/month}$, 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.

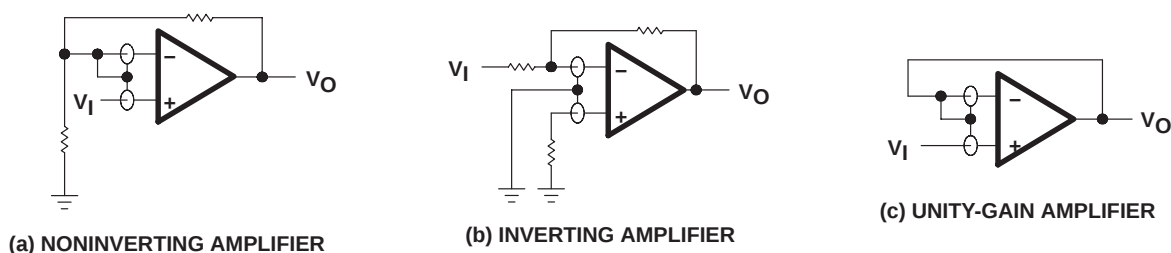


Figure 40. Guard-Ring Schemes

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-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 60Ω and 180Ω , 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)

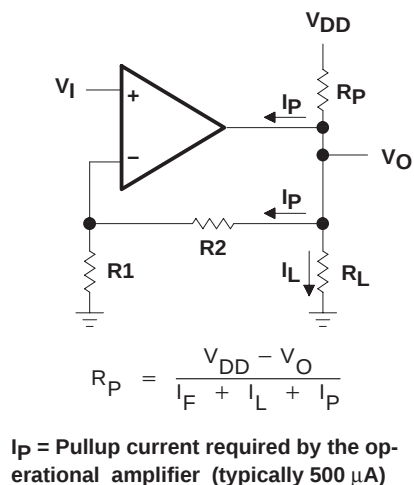


Figure 42. Resistive Pullup to Increase V_{OH}



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

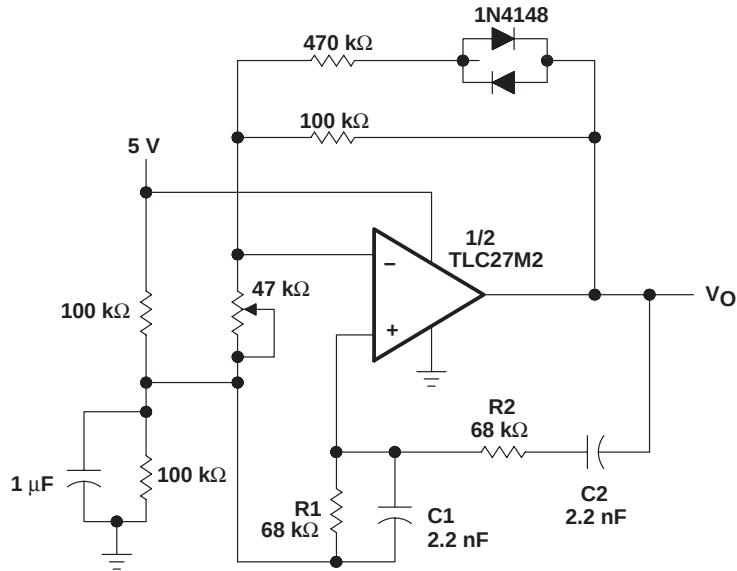
The TLC27M2 and TLC27M7 incorporate an internal electrostatic-discharge (ESD) protection circuit that prevents functional failures at voltages up to 2000 V as tested under MIL-STD-883C, Method 3015.2. Care should be exercised, however, when handling these devices as exposure to ESD may result in the 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 μ 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.

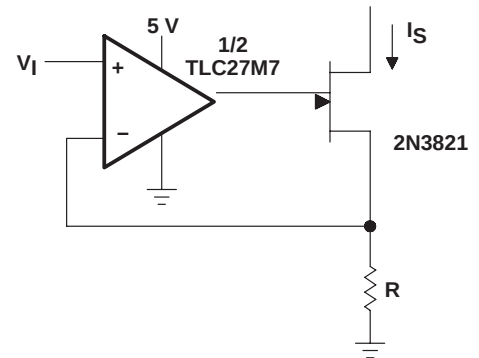
APPLICATION INFORMATION



NOTES: $V_{O(PP)} \approx 2\text{ V}$

$$f_O = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

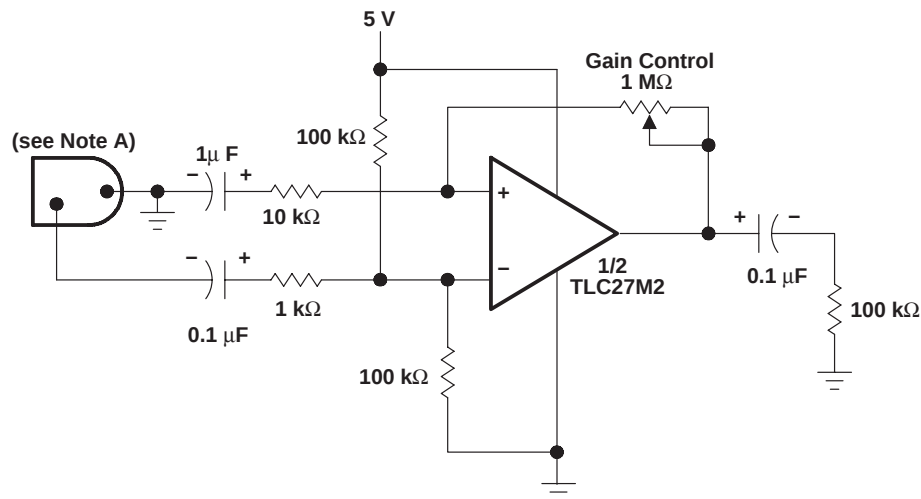
Figure 44. Wien Oscillator



NOTES: $V_I = 0\text{ V to } 3\text{ V}$

$$I_S = \frac{V_I}{R}$$

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

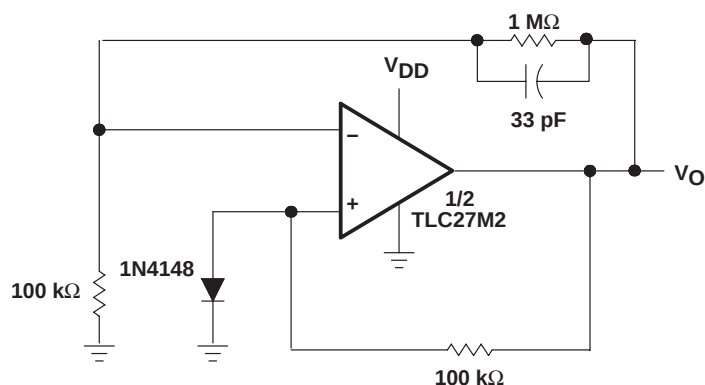
SLOS051E – OCTOBER 1987 – REVISED AUGUST 2008

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

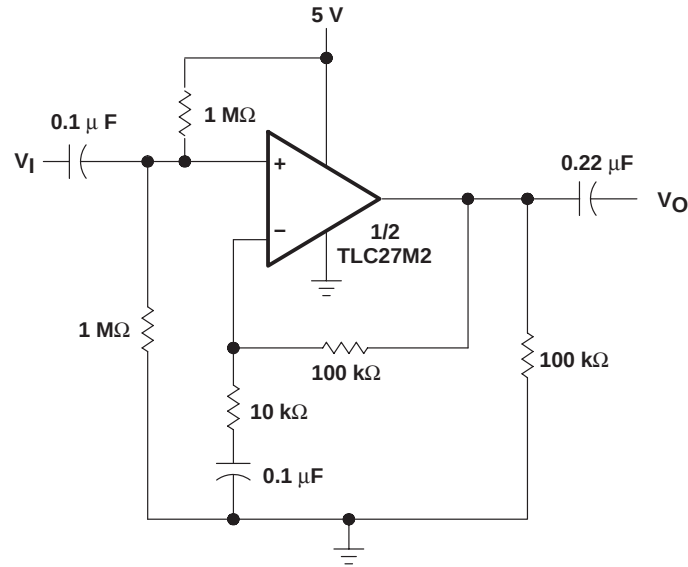


Figure 49. Single-Rail AC Amplifiers

PACKAGING INFORMATION

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/ Ball Finish	MSL Peak Temp ⁽³⁾	Samples (Requires Login)
TLC27M2ACD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2ACDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2ACDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2ACDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2ACP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2ACPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2AID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2AIDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2AIDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2AIDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2AIP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2AIPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2BCD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2BCDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2BCDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2BCDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2BCP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2BCPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2BID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/ Ball Finish	MSL Peak Temp ⁽³⁾	Samples (Requires Login)
TLC27M2BIDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2BIDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2BIDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2BIP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2BIPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2CD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2CDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2CDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2CDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2CP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2CPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2CPSLE	OBSOLETE	SO	PS	8		TBD	Call TI	Call TI	
TLC27M2CPSR	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2CPSRG4	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2CPW	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2CPWG4	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2CPWLE	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	
TLC27M2CPWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2CPWRG4	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2ID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/ Ball Finish	MSL Peak Temp ⁽³⁾	Samples (Requires Login)
TLC27M2IDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2IDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2IP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2IPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M2IPW	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2IPWG4	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2IPWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2IPWRG4	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2MD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2MDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M2MFKB	OBSOLETE	LCCC	FK	20		TBD	Call TI	Call TI	
TLC27M2MJG	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI	
TLC27M2MJGB	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI	
TLC27M7CD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M7CDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M7CDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M7CDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M7CP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M7CPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M7CPSR	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/ Ball Finish	MSL Peak Temp ⁽³⁾	Samples (Requires Login)
TLC27M7CPSRG4	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M7ID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M7IDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M7IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M7IDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLC27M7IP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M7IPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	
TLC27M7MFKB	OBSOLETE	LCCC	FK	20		TBD	Call TI	Call TI	
TLC27M7MJG	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI	
TLC27M7MJGB	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI	
TLC27M7MUB	OBSOLETE	CFP	U	10		TBD	Call TI	Call TI	

⁽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⁾ Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

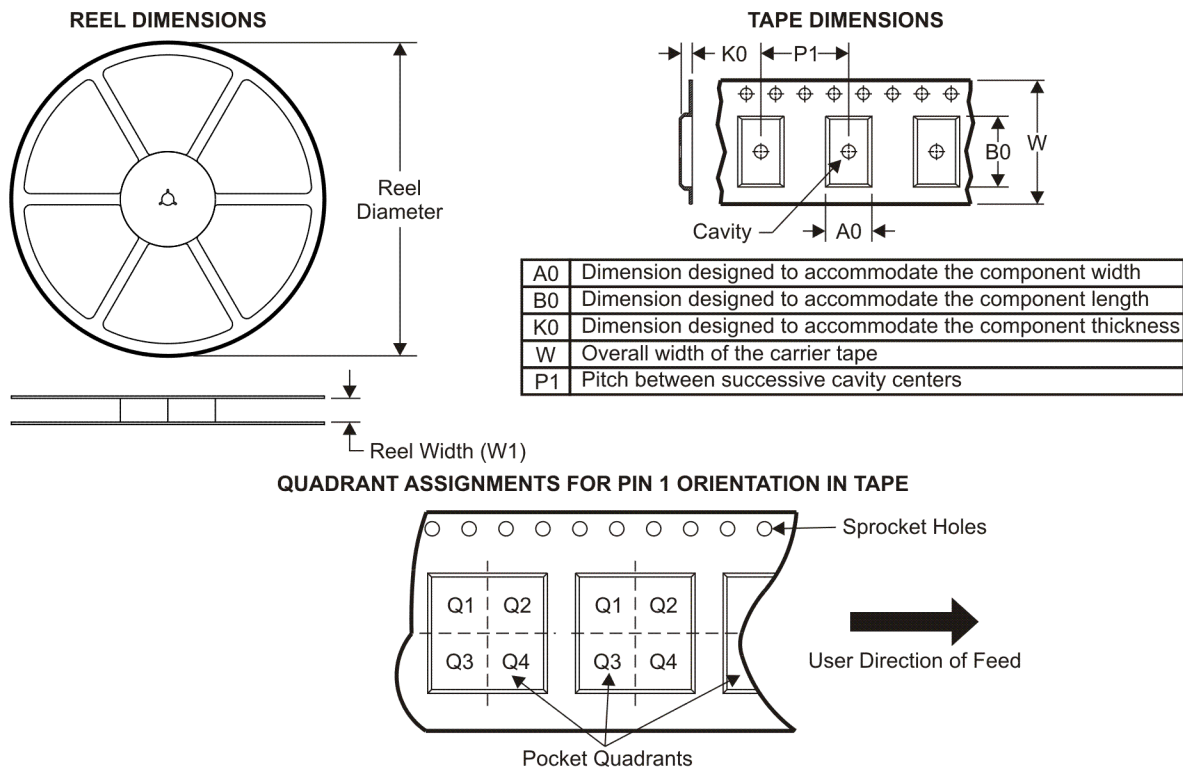
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION


*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
TLC27M2CDR	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	8.2	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
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
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	8.2	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

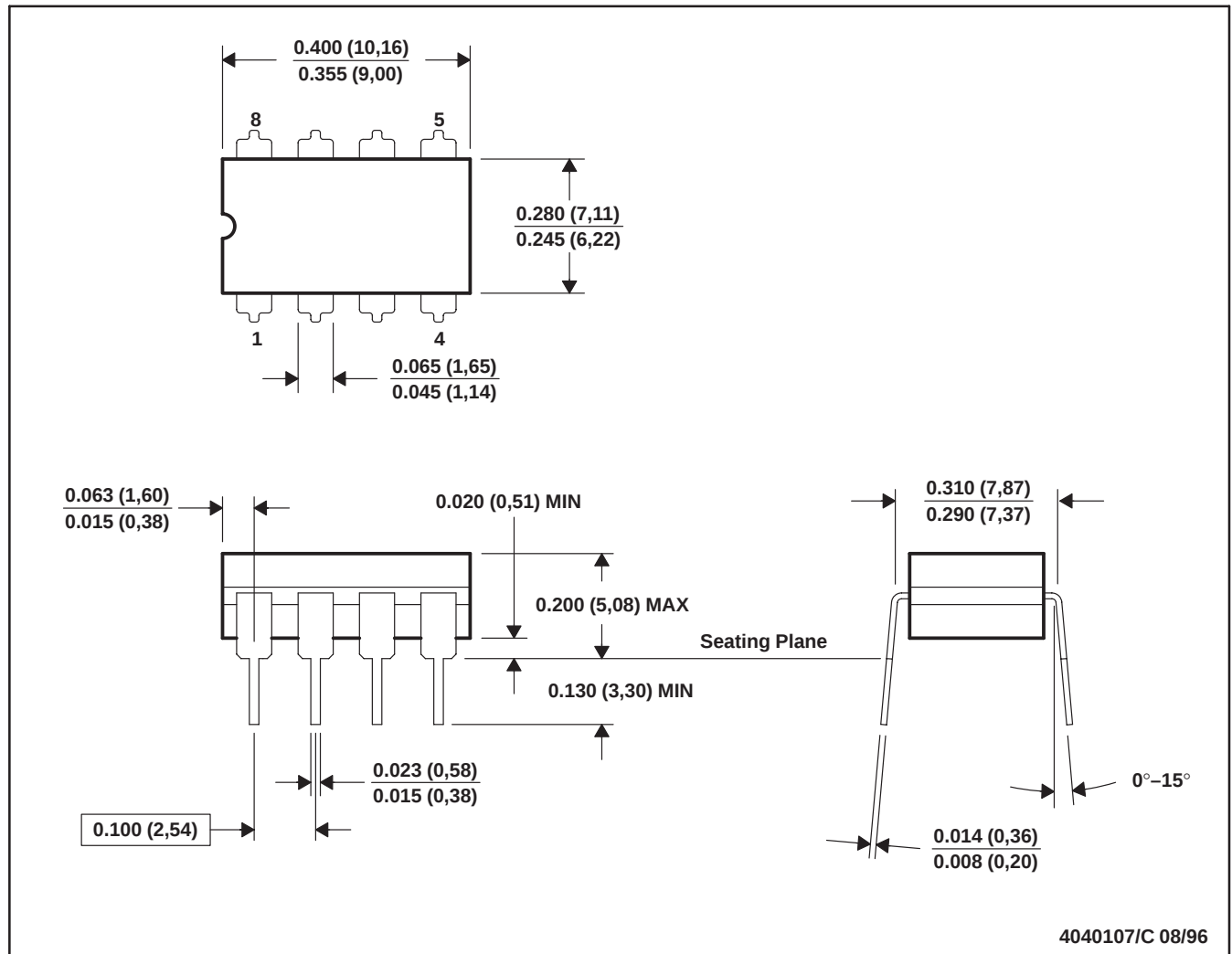


*All dimensions are nominal

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	346.0	346.0	33.0
TLC27M2CPWR	TSSOP	PW	8	2000	346.0	346.0	29.0
TLC27M2IDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC27M2IPWR	TSSOP	PW	8	2000	346.0	346.0	29.0
TLC27M7CDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC27M7CPSR	SO	PS	8	2000	346.0	346.0	33.0
TLC27M7IDR	SOIC	D	8	2500	340.5	338.1	20.6

JG (R-GDIP-T8)

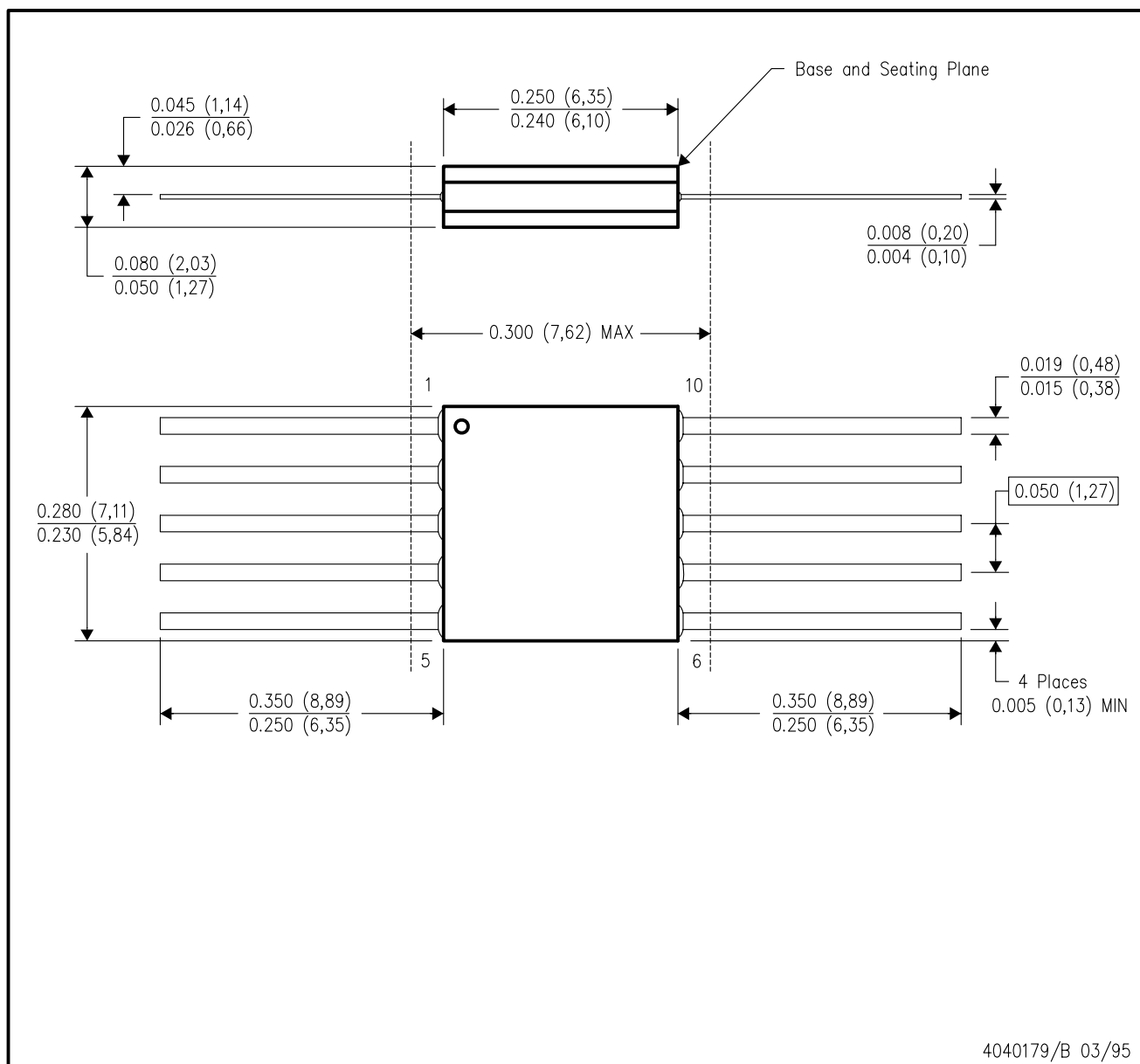
CERAMIC DUAL-IN-LINE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - C. This package can be hermetically sealed with a ceramic lid using glass frit.
 - D. Index point is provided on cap for terminal identification.
 - E. Falls within MIL STD 1835 GDIP1-T8

U (S-GDFP-F10)

CERAMIC DUAL FLATPACK

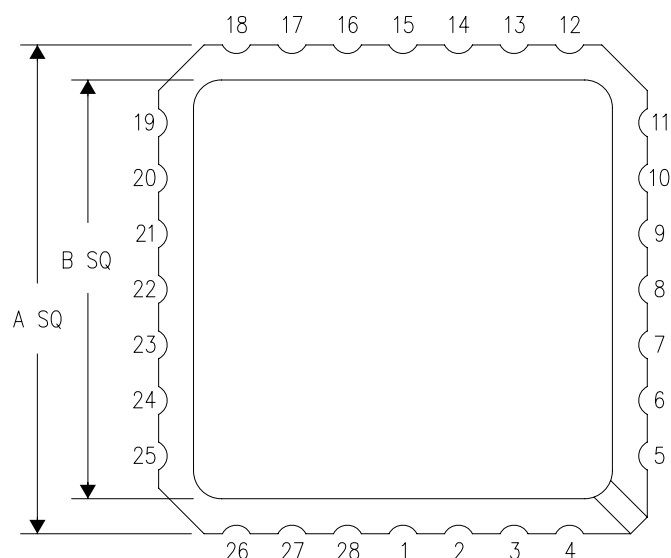


- NOTES:
- All linear dimensions are in inches (millimeters).
 - This drawing is subject to change without notice.
 - This package can be hermetically sealed with a ceramic lid using glass frit.
 - Index point is provided on cap for terminal identification only.
 - Falls within MIL STD 1835 GDFP1-F10 and JEDEC MO-092AA

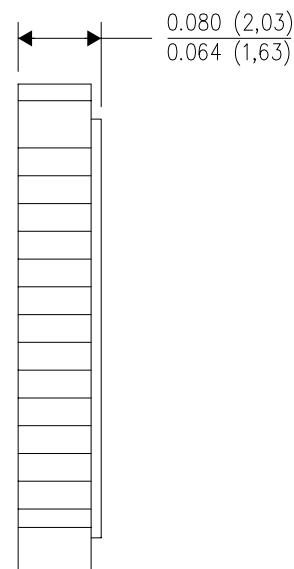
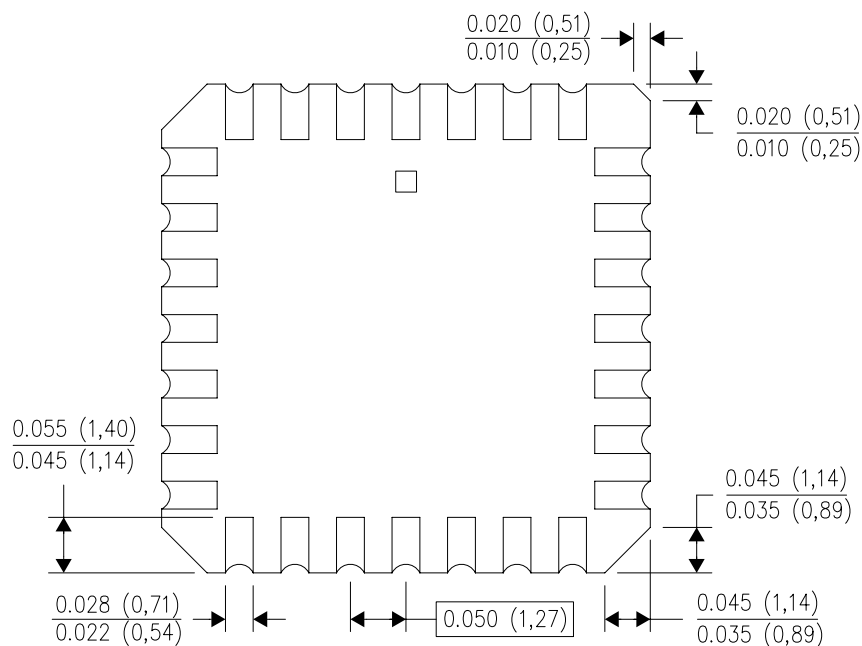
FK (S-CQCC-N**)

LEADLESS CERAMIC CHIP CARRIER

28 TERMINAL SHOWN



NO. OF TERMINALS **	A		B	
	MIN	MAX	MIN	MAX
20	0.342 (8,69)	0.358 (9,09)	0.307 (7,80)	0.358 (9,09)
28	0.442 (11,23)	0.458 (11,63)	0.406 (10,31)	0.458 (11,63)
44	0.640 (16,26)	0.660 (16,76)	0.495 (12,58)	0.560 (14,22)
52	0.740 (18,78)	0.761 (19,32)	0.495 (12,58)	0.560 (14,22)
68	0.938 (23,83)	0.962 (24,43)	0.850 (21,6)	0.858 (21,8)
84	1.141 (28,99)	1.165 (29,59)	1.047 (26,6)	1.063 (27,0)



4040140/D 01/11

- NOTES:
- All linear dimensions are in inches (millimeters).
 - This drawing is subject to change without notice.
 - This package can be hermetically sealed with a metal lid.
 - Falls within JEDEC MS-004

P (R-PDIP-T8)

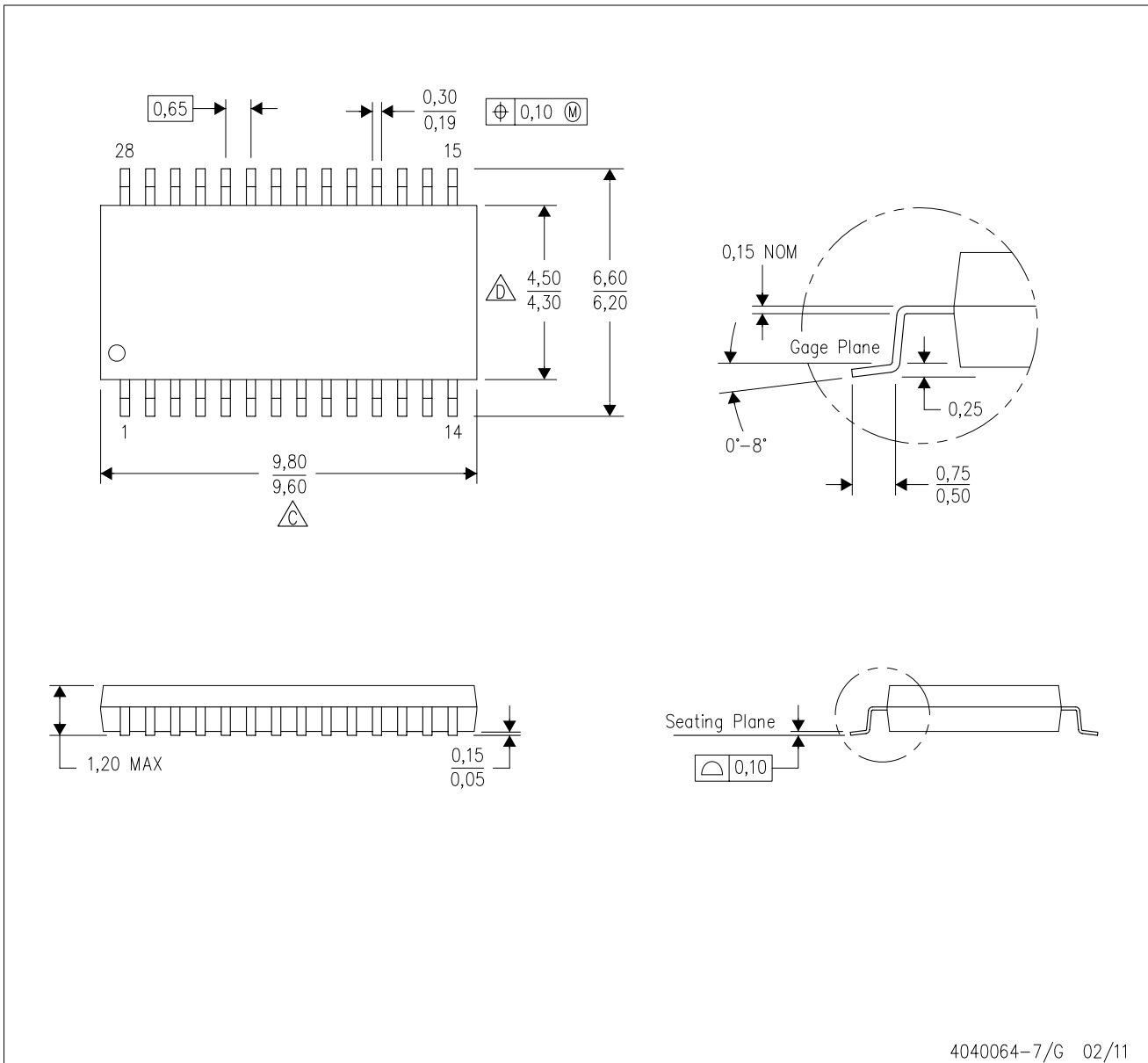
PLASTIC DUAL-IN-LINE PACKAGE



- 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.

PW (R-PDSO-G28)

PLASTIC SMALL OUTLINE

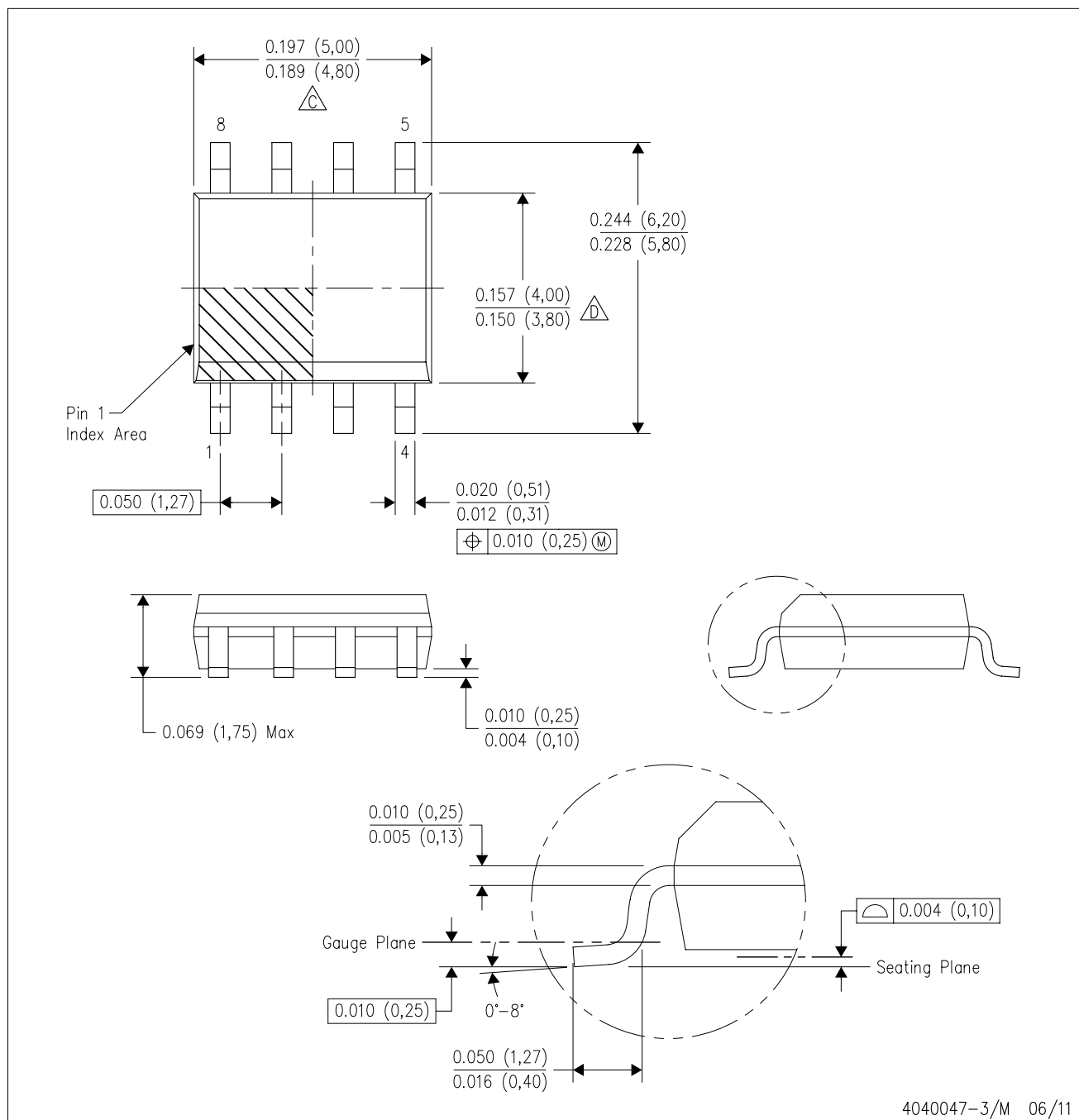


4040064-7/G 02/11

- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
 - B. This drawing is subject to change without notice.
 - C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0,15 each side.
 - D. Body width does not include interlead flash. Interlead flash shall not exceed 0,25 each side.
 - E. Falls within JEDEC MO-153

D (R-PDSO-G8)

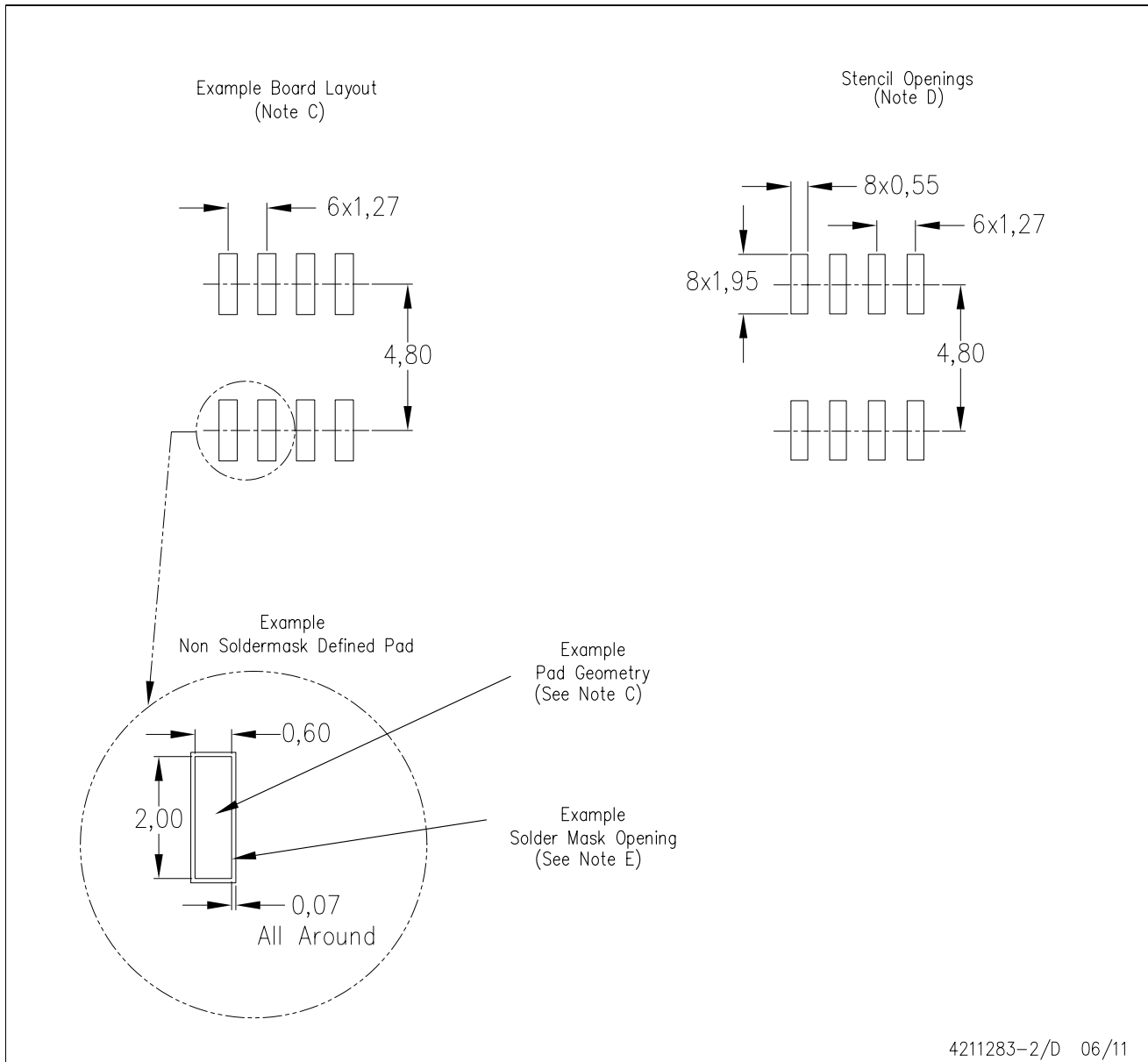
PLASTIC SMALL OUTLINE



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

D (R-PDSO-G8)

PLASTIC SMALL OUTLINE



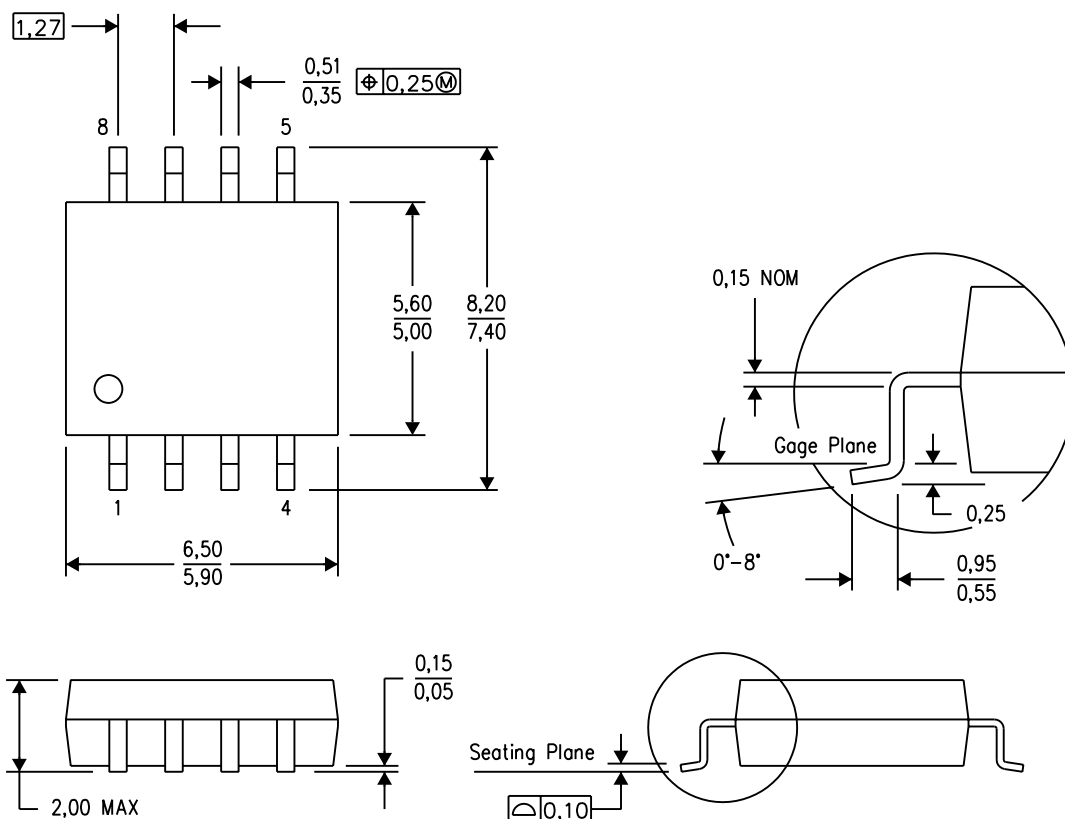
4211283-2/D 06/11

- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Publication IPC-7351 is recommended for alternate designs.
 - D. 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.
 - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

MECHANICAL DATA

PS (R-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE

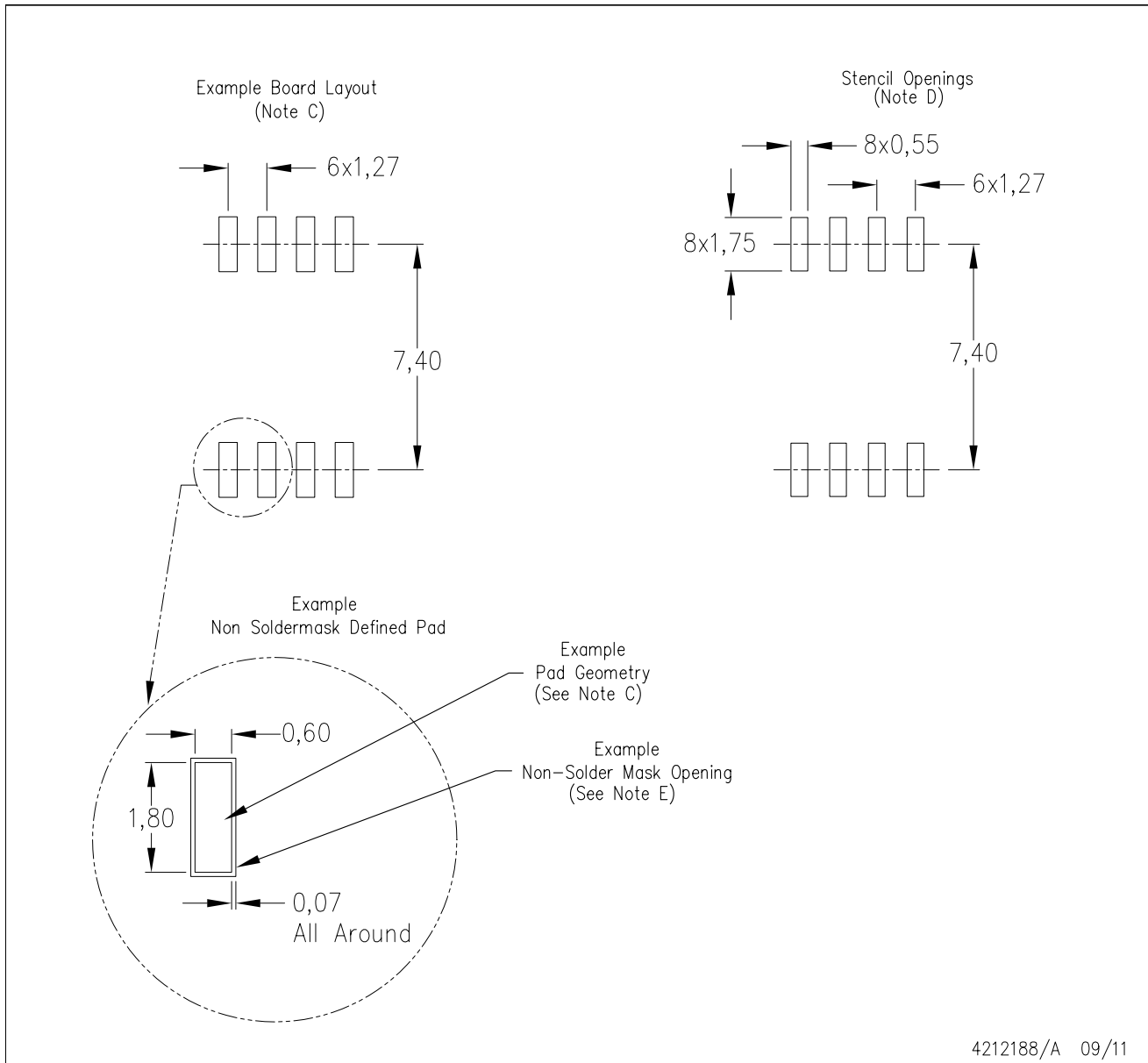


4040063/C 03/03

- 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)

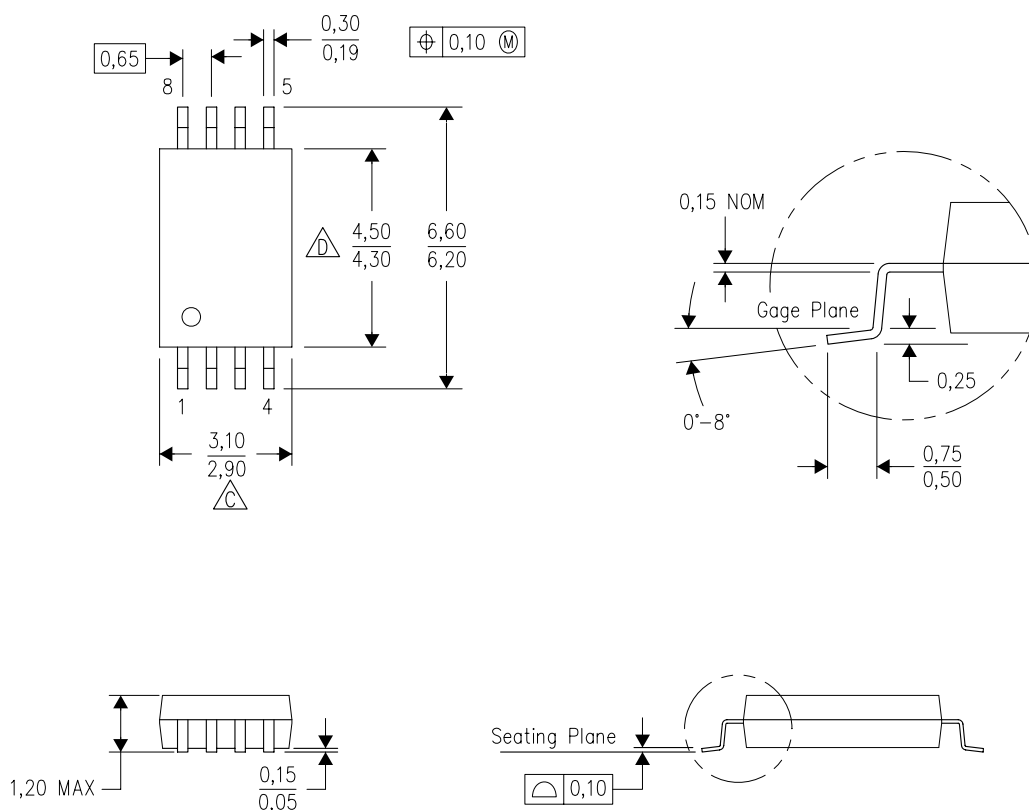
PLASTIC SMALL OUTLINE



- 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.

PW (R-PDSO-G8)

PLASTIC SMALL OUTLINE



4040064-2/G 02/11

- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
 - B. This drawing is subject to change without notice.
 - C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0,15 each side.
 - D. Body width does not include interlead flash. Interlead flash shall not exceed 0,25 each side.
 - E. Falls within JEDEC MO-153

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