

TLV277x, TLV277xA

FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS WITH SHUTDOWN

SLOS209F – JANUARY 1998 – REVISED MARCH 2001

- High Slew Rate . . . 10.5 V/μs Typ
- High-Gain Bandwidth . . . 5.1 MHz Typ
- Supply Voltage Range 2.5 V to 5.5 V
- Rail-to-Rail Output
- 360 μV Input Offset Voltage
- Low Distortion Driving 600-Ω
0.005% THD+N
- 1 mA Supply Current (Per Channel)
- 17 nV/√Hz Input Noise Voltage
- 2 pA Input Bias Current
- Characterized From T_A = –55°C to 125°C
- Available in MSOP and SOT-23 Packages
- Micropower Shutdown Mode . . . I_{DD} < 1 μA
- Available in Q-Temp Automotive
High Reliability Automotive Applications
Configuration Control / Print Support
Qualification to Automotive Standards

description

The TLV277x CMOS operational amplifier family combines high slew rate and bandwidth, rail-to-rail output swing, high output drive, and excellent dc precision. The device provides 10.5 V/μs of slew rate and 5.1 MHz of bandwidth while only consuming 1 mA of supply current per channel. This ac performance is much higher than current competitive CMOS amplifiers. The rail-to-rail output swing and high output drive make these devices a good choice for driving the analog input or reference of analog-to-digital converters. These devices also have low distortion while driving a 600-Ω load for use in telecom systems.

These amplifiers have a 360-μV input offset voltage, a 17 nV/√Hz input noise voltage, and a 2-pA input bias current for measurement, medical, and industrial applications. The TLV277x family is also specified across an extended temperature range (–40°C to 125°C), making it useful for automotive systems, and the military temperature range (–55°C to 125°C), for military systems.

These devices operate from a 2.5-V to 5.5-V single supply voltage and are characterized at 2.7 V and 5 V. The single-supply operation and low power consumption make these devices a good solution for portable applications. The following table lists the packages available.

FAMILY PACKAGE TABLE

DEVICE	NUMBER OF CHANNELS	PACKAGE TYPES								SHUTDOWN	UNIVERSAL EVM BOARD
		PDIP	CDIP	SOIC	SOT-23	TSSOP	MSOP	LCCC	CPAK		
TLV2770	1	8	—	8	—	—	8	—	—	Yes	Refer to the EVM Selection Guide (Lit# SLOU060)
TLV2771	1	—	—	8	5	—	—	—	—	—	
TLV2772	2	8	8	8	—	8	8	20	10	—	
TLV2773	2	14	—	14	—	—	10	—	—	Yes	
TLV2774	4	14	—	14	—	14	—	—	—	—	
TLV2775	4	16	—	16	—	16	—	—	—	Yes	

A SELECTION OF SINGLE-SUPPLY OPERATIONAL AMPLIFIER PRODUCTST

DEVICE	V _{DD} (V)	BW (MHz)	SLEW RATE (V/μs)	I _{DD} (per channel) (μA)	RAIL-TO-RAIL
TLV277X	2.5 – 6.0	5.1	10.5	1000	O
TLV247X	2.7 – 6.0	2.8	1.5	600	I/O
TLV245X	2.7 – 6.0	0.22	0.11	23	I/O
TLV246X	2.7 – 6.0	6.4	1.6	550	I/O

† All specifications measured at 5 V.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

This document contains information on products in more than one phase of development. The status of each device is indicated on the page(s) specifying its electrical characteristics.



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On products compliant to MIL-PRF-38535, all parameters are tested unless otherwise noted. On all other products, production processing does not necessarily include testing of all parameters.

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TLV2770 and TLV2771 AVAILABLE OPTIONS

T _A	V _{IOmax} AT 25°C (mV)	PACKAGED DEVICES			
		SMALL OUTLINE (D)	SOT-23 (DBV)	MSOP (DGK)	PLASTIC DIP (P)
0°C to 70°C	2.5	TLV2770CD TLV2771CD	— TLV2771CDBV	TLV2770CDGK† —	TLV2770CP —
–40°C to 125°C	2.5	TLV2770ID TLV2771ID	— TLV2771IDBV	TLV2770IDGK† —	TLV2770IP —
	1.6	TLV2770AID TLV2771AID	— —	— —	TLV2770AIP —

† This device is in the Product Preview stage of development. Please contact your local TI sales office for availability.

TLV2772 and TLV2773 AVAILABLE OPTIONS

T _A	V _{IOmax} AT 25°C (mV)	PACKAGED DEVICES				
		SMALL OUTLINE (D)	MSOP (DGK)	MSOP (DGS)	PLASTIC DIP (N)	PLASTIC DIP (P)
0°C to 70°C	2.5	TLV2772CD TLV2773CD	TLV2772CDGK —	— TLV2773CDGS	— TLV2773CN	TLV2772CP —
–40°C to 125°C	2.5	TLV2772ID TLV2773ID	TLV2772IDGK —	— TLV2773IDGS	— TLV2773IN	TLV2772IP —
	1.6	TLV2772AID TLV2773AID	— —	— —	— TLV2773AIN	TLV2772AIP —

TLV2774 and TLV2775 AVAILABLE OPTIONS

T _A	V _{IOmax} AT 25°C (mV)	PACKAGED DEVICES			
		SMALL OUTLINE (D)	PLASTIC DIP (N)	PLASTIC DIP (P)	TSSOP (PW)
0°C to 70°C	2.7	TLV2774CD TLV2775CD	— TLV2775CN	TLV2774CP —	TLV2774CPW TLV2775CPW
–40°C to 125°C	2.7	TLV2774ID TLV2775ID	— TLV2775IN	TLV2774IP —	TLV2774IPW TLV2775IPW
	2.1	TLV2774AID TLV2775AID	— TLV2775AIN	TLV2774AIP —	TLV2774AIPW TLV2775AIPW

TLV2772M/Q AND TLV2772AM/Q AVAILABLE OPTIONS

T _A	V _{IOmax} AT 25°C (mV)	PACKAGED DEVICES				
		SMALL OUTLINE (D)	CHIP CARRIER (FK)	CERAMIC DIP (JG)	CERAMIC FLATPACK (U)	TSSOP (PW)
–40°C to 125°C	2.5	TLV2772QD‡	—	—	—	TLV2772QPW‡
	1.6	TLV2772AQD‡	—	—	—	TLV2772AQPW‡
–55°C to 125°C	2.5	TLV2772MD	TLV2772MFK	TLV2772MJG	TLV2772MU	—
	1.6	TLV2772AMD	TLV2772AMFK	TLV2772AMJG	TLV2772AMU	—

‡ Available in tape and reel



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PACKAGE SYMBOLS

PACKAGE TYPE	PINS	PART NUMBER	SYMBOL†
SOT23	5 Pin	TLV2771CDBV	VAMC
		TLV2771IDBV	VAMI
MSOP	8 Pin	TLV2770CDGK	xxTIABO
		TLV2770IDGK	xxTIABP
		TLV2772CDGK	xxTIAAF
		TLV2772IDGK	xxTIAAG
	10 Pin	TLV2773CDGS	xxTIABQ
		TLV2773IDGS	xxTIABR

† xx represents the device date code.



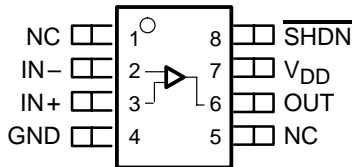
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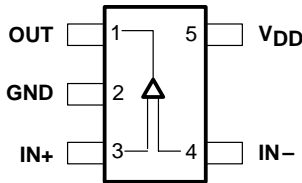
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TLV277x PACKAGE PINOUTS

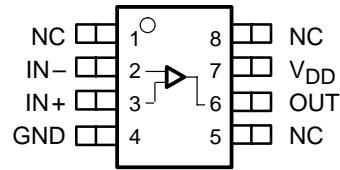
TLV2770
D, DGK† OR P PACKAGE
(TOP VIEW)



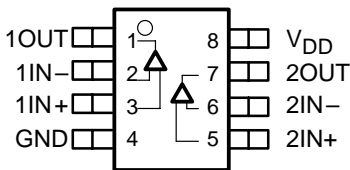
TLV2771
DBV PACKAGE
(TOP VIEW)



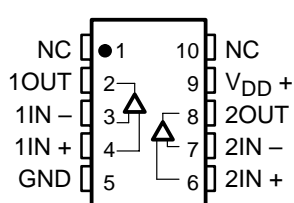
TLV2771
D PACKAGE
(TOP VIEW)



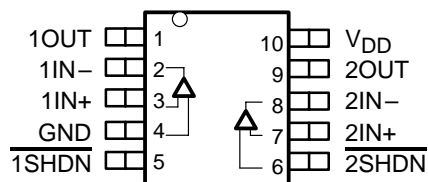
TLV2772
D, DGK, JG, P, OR PW PACKAGE
(TOP VIEW)



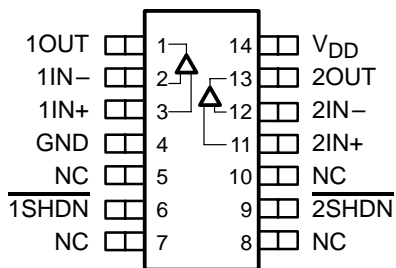
TLV2772M AND TLV2772AM
U PACKAGE
(TOP VIEW)



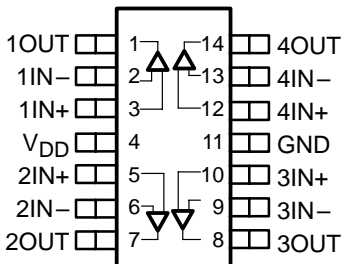
TLV2773
DGS PACKAGE
(TOP VIEW)



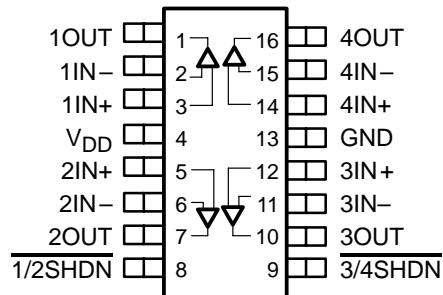
TLV2773
D OR N PACKAGE
(TOP VIEW)



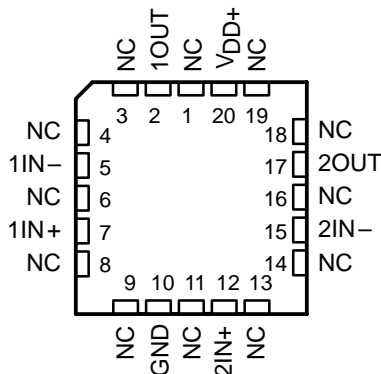
TLV2774
D, N, OR PW PACKAGE
(TOP VIEW)



TLV2775
D, N, OR PW PACKAGE
(TOP VIEW)



TLV2772M AND TLV2772AM
FK PACKAGE
(TOP VIEW)



NC – No internal connection

† This device is in the Product Preview stage of development. Please contact your local TI sales office for availability.

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

Supply voltage, V_{DD} (see Note 1)	7 V
Differential input voltage, V_{ID} (see Note 2)	$\pm V_{DD}$
Input voltage range, V_I (any input, see Note 1)	-0.3 V to V_{DD}
Input current, I_I (any input)	± 4 mA
Output current, I_O	± 50 mA
Total current into V_{DD+}	± 50 mA
Total current out of GND	± 50 mA
Duration of short-circuit current (at or below) 25°C (see Note 3)	unlimited
Continuous total power dissipation	See Dissipation Rating Table
Operating free-air temperature range, T_A : C suffix	0°C to 70°C
I suffix	-40°C to 125°C
Q suffix	-40°C to 125°C
M suffix	-55°C to 125°C
Storage temperature range, T_{stg}	-65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	260°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:
- All voltage values, except differential voltages, are with respect to GND.
 - Differential voltages are at the noninverting input with respect to the inverting input. Excessive current flows when input is brought below GND - 0.3 V.
 - 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.

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	145 mW
DBV	437 mW	3.5 mW/°C	280 mW	227 mW	87 mW
DGK	424 mW	3.4 mW/°C	271 mW	220 mW	85 mW
DGS	424 mW	3.4 mW/°C	271 mW	220 mW	85 mW
FK	1375 mW	11.0 mW/°C	672 mW	546 mW	210 mW
JG	1050 mW	8.4 mW/°C	880 mW	714 mW	275 mW
N	1150 mW	9.2 mW/°C	736 mW	598 mW	230 mW
P	1000 mW	8.0 mW/°C	640 mW	520 mW	200 mW
PW	700 mW	5.6 mW/°C	448 mW	364 mW	140 mW
U	675 mW	5.4 mW/°C	432 mW	350 mW	135 mW

recommended operating conditions

	C SUFFIX		I SUFFIX		Q SUFFIX		M SUFFIX		UNIT
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	
Supply voltage, V_{DD}	2.5	6	2.5	6	2.5	6	2.5	6	V
Input voltage range, V_I	GND	$V_{DD+} - 1.3$	GND	$V_{DD+} - 1.3$	GND	$V_{DD+} - 1.3$	GND	$V_{DD+} - 1.3$	V
Common-mode input voltage, V_{IC}	GND	$V_{DD+} - 1.3$	GND	$V_{DD+} - 1.3$	GND	$V_{DD+} - 1.3$	GND	$V_{DD+} - 1.3$	V
Operating free-air temperature, T_A	0	70	-40	125	-40	125	-55	125	°C



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electrical characteristics at specified free-air temperature, $V_{DD} = 2.7\text{ V}$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	T_A †	TLV277xC			UNIT
				MIN	TYP	MAX	
V_{IO}	Input offset voltage	$V_{IC} = 0,$ $R_S = 50\ \Omega,$	$V_O = 0,$ $V_{DD} = \pm 1.35\text{ V}$	25°C	0.44	2.5	mV
				Full range	0.47	2.7	
				25°C	0.8	2.7	
				Full range	0.86	2.9	
α_{VIO}	Temperature coefficient of input offset voltage			25°C to 125°C	2		$\mu\text{V}/^\circ\text{C}$
I_{IO}	Input offset current	$V_{IC} = 0,$ $R_S = 50\ \Omega$	$V_O = 0,$ $V_{DD} = \pm 1.35\text{ V}$	25°C	1	60	pA
				Full range	2	100	
I_{IB}	Input bias current			25°C	2	60	pA
				Full range	6	100	
V_{ICR}	Common-mode input voltage range	CMRR > 70 dB,	$R_S = 50\ \Omega$	25°C	0 to 1.4	-0.3 to 1.7	V
				Full range	0 to 1.4	-0.3 to 1.7	
V_{OH}	High-level output voltage			25°C	2.6		V
				Full range	2.5		
				25°C	2.4		
				Full range	2.1		
V_{OL}	Low-level output voltage	$V_{IC} = 1.35\text{ V},$	$I_{OL} = 0.675\text{ mA}$	25°C	0.1		V
				Full range	0.2		
		$V_{IC} = 1.35\text{ V},$	$I_{OL} = 2.2\text{ mA}$	25°C	0.21		
				Full range	0.6		
A_{VD}	Large-signal differential voltage amplification	$V_{IC} = 1.35\text{ V},$ $V_O = 0.6\text{ V to } 2.1\text{ V}$	$R_L = 10\text{ k}\Omega,$	25°C	20	380	V/mV
				Full range	13		
$r_{i(d)}$	Differential input resistance			25°C	10^{12}		Ω
$c_{i(c)}$	Common-mode input capacitance	$f = 10\text{ kHz}$		25°C	8		pF
z_o	Closed-loop output impedance	$f = 100\text{ kHz},$	$A_V = 10$	25°C	25		Ω
CMRR	Common-mode rejection ratio	$V_{IC} = 0\text{ to } 1.5\text{ V},$ $R_S = 50\ \Omega$	$V_O = 1.5\text{ V},$	25°C	70	84	dB
				Full range	70	82	
k_{SVR}	Supply voltage rejection ratio ($\Delta V_{DD} / \Delta V_{IO}$)	$V_{DD} = 2.7\text{ V to } 5\text{ V},$ No load	$V_{IC} = V_{DD}/2,$	25°C	70	89	dB
				Full range	70	84	
I_{DD}	Supply current (per channel)	$V_O = 1.5\text{ V},$	No load	25°C	1	2	mA
				Full range	2		
$I_{DD(SHDN)}$	Supply current in shutdown (per channel)			25°C	0.8	1.5	μA
				Full range	1.3	2	
$V_{(ON)}$	Turnon voltage level	TLV2770	$A_V = 5$	25°C	1.47		V
		TLV2773			1.43		
		TLV2775			1.40		
$V_{(OFF)}$	Turnoff voltage level	TLV2770	$A_V = 5$	25°C	1.27		V
		TLV2773			1.21		
		TLV2775			1.20		

† Full range is 0°C to 70°C.



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operating characteristics at specified free-air temperature, $V_{DD} = 2.7\text{ V}$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		T_A †	TLV277xC			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	$V_{O(PP)} = 0.8\text{ V}$, $R_L = 10\text{ k}\Omega$	$C_L = 100\text{ pF}$	25°C	5	9	V/ μs	
				Full range	4.7	6		
V_n	Equivalent input noise voltage			25°C	21		nV/ $\sqrt{\text{Hz}}$	
				25°C	17			
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage			25°C	0.33		μV	
					0.86			
I_n	Equivalent input noise current		$f = 100\text{ Hz}$	25°C	0.6		fA/ $\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise	$R_L = 600\ \Omega$, $f = 1\text{ kHz}$		25°C	$A_V = 1$	0.0085%		
					$A_V = 10$	0.025%		
					$A_V = 100$	0.12%		
Gain-bandwidth product			$f = 10\text{ kHz}$, $C_L = 100\text{ pF}$	$R_L = 600\ \Omega$, 25°C	4.8		MHz	
t_s	Settling time	$A_V = -1$, Step = 1 V, $R_L = 600\ \Omega$, $C_L = 100\text{ pF}$		25°C	0.1%	0.186		μs
				25°C	0.01%	0.3		
ϕ_m	Phase margin at unity gain	$R_L = 600\ \Omega$, $C_L = 100\text{ pF}$		25°C	46°			
	Gain margin			25°C	12		dB	

† Full range is 0°C to 70°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 †	TLV277xC			UNIT
				MIN	TYP	MAX	
V_{IO}	Input offset voltage	$V_{IC} = 0,$ $R_S = 50\ \Omega$	$V_O = 0,$ $V_{DD} = \pm 2.5\text{ V}$	25°C	0.36	2.5	mV
				Full range	0.4	2.7	
				25°C	0.7	2.5	
				Full range	0.78	2.7	
α_{VIO}	Temperature coefficient of input offset voltage			25°C to 125°C	2		$\mu\text{V}/^\circ\text{C}$
I_{IO}	Input offset current	$V_{IC} = 0,$ $R_S = 50\ \Omega$	$V_O = 0,$ $V_{DD} = \pm 2.5\text{ V}$	25°C	1	60	pA
				Full range	2	100	
I_{IB}	Input bias current			25°C	2	60	pA
				Full range	6	100	
V_{ICR}	Common-mode input voltage range	CMRR > 60 dB,	$R_S = 50\ \Omega$	25°C	0 to 3.7	-0.3 to 3.8	V
				Full range	0 to 3.7	-0.3 to 3.8	
V_{OH}	High-level output voltage	$I_{OH} = -1.3\text{ mA}$		25°C	4.9		V
				Full range	4.8		
		$I_{OH} = -4.2\text{ mA}$		25°C	4.7		
				Full range	4.4		
V_{OL}	Low-level output voltage	$V_{IC} = 2.5\text{ V},$	$I_{OL} = 1.3\text{ mA}$	25°C	0.1		V
				Full range	0.2		
		$V_{IC} = 2.5\text{ V},$	$I_{OL} = 4.2\text{ mA}$	25°C	0.21		
				Full range	0.6		
A_{VD}	Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V},$ $V_O = 1\text{ V to }4\text{ V}$	$R_L = 10\text{ k}\Omega,$	25°C	20	450	V/mV
				Full range	13		
$r_{i(d)}$	Differential input resistance			25°C	10 ¹²		Ω
$C_{i(c)}$	Common-mode input capacitance	$f = 10\text{ kHz}$		25°C	8		pF
z_o	Closed-loop output impedance	$f = 100\text{ kHz},$	$A_V = 10$	25°C	20		Ω
CMRR	Common-mode rejection ratio	$V_{IC} = 0\text{ to }3.7\text{ V},$ $R_S = 50\ \Omega$	$V_O = 3.7\text{ V},$	25°C	60	96	dB
				Full range	60	93	
k_{SVR}	Supply voltage rejection ratio ($\Delta V_{DD} / \Delta V_{IO}$)	$V_{DD} = 2.7\text{ V to }5\text{ V},$ No load	$V_{IC} = V_{DD}/2,$	25°C	70	89	dB
				Full range	70	84	
I_{DD}	Supply current (per channel)	$V_O = 1.5\text{ V},$	No load	25°C	1	2	mA
				Full range	2		
$I_{DD(SHDN)}$	Supply current in shutdown (per channel)			25°C	0.8	1.5	μA
				Full range	1.3	2	
$V_{(ON)}$	Turnon voltage level	TLV2770	$A_V = 5$	25°C	2.59		V
		TLV2773			2.47		
		TLV2775			2.48		
$V_{(OFF)}$	Turnoff voltage level	TLV2770	$A_V = 5$	25°C	2.41		V
		TLV2773			2.32		
		TLV2775			2.29		

† Full range is 0°C to 70°C.



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

PARAMETER		TEST CONDITIONS		T_A †	TLV277xC			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	$V_{O(PP)} = 1.5\text{ V}$, $R_L = 10\text{ k}\Omega$	$C_L = 100\text{ pF}$	25°C	5	10.5	V/ μs	
				Full range	4.7	6		
V_n	Equivalent input noise voltage	f = 1 kHz		25°C	17		nV/ $\sqrt{\text{Hz}}$	
		f = 10 kHz		25°C	12			
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	f = 0.1 Hz to 1 Hz		25°C	0.33		μV	
		f = 0.1 Hz to 10 Hz			0.86			
I_n	Equivalent input noise current	f = 100 Hz		25°C	0.6		fA/ $\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise	$R_L = 600\ \Omega$, f = 1 kHz		$A_V = 1$	25°C	0.005%		
				$A_V = 10$		0.016%		
				$A_V = 100$		0.095%		
Gain-bandwidth product		f = 10 kHz, $C_L = 100\text{ pF}$	$R_L = 600\ \Omega$	25°C	5.1		MHz	
t_s	Settling time	$A_V = -1$, Step = 2 V, $R_L = 600\ \Omega$, $C_L = 100\text{ pF}$		0.1%	25°C	0.335		μs
				0.01%	25°C	0.6		
ϕ_m	Phase margin at unity gain	$R_L = 600\ \Omega$, $C_L = 100\text{ pF}$		25°C	46°			
	Gain margin			25°C	12		dB	
$t_{(ON)}$	Amplifier turnon time	$A_V = 5$, $R_L = \text{Open}$, Measured to 50% point		25°C	TLV2770		1.2	μs
					TLV2773		2.4	
					TLV2775		1.9	
$t_{(OFF)}$	Amplifier turnoff time	$A_V = 5$, $R_L = \text{Open}$, Measured to 50% point		25°C	TLV2770		335	ns
					TLV2773		444	
					TLV2775		345	

† Full range is 0°C to 70°C.

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electrical characteristics at specified free-air temperature, $V_{DD} = 2.7\text{ V}$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	T_A †	TLV277xI			TLV277xAI			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	$V_{IC} = 0, V_O = 0,$ $R_S = 50\ \Omega$ $V_{DD} = \pm 1.35\text{ V}$	25°C	0.44	2.5		0.44	1.6	mV	
			Full range	0.47	2.7		0.47	1.9		
			25°C	0.8	2.7		0.8	2.1		
			Full range	0.86	2.9		0.86	2.2		
α_{VIO}	Temperature coefficient of input offset voltage		25°C to 125°C	2			2			$\mu\text{V}/^\circ\text{C}$
I_{IO}	Input offset current	$V_{IC} = 0, V_O = 0,$ $R_S = 50\ \Omega$	25°C	1	60		1	60	pA	
			Full range	2	125		2	125		
I_{IB}	Input bias current		25°C	2	60		2	60	pA	
			Full range	6	350		6	350		
V_{ICR}	Common-mode input voltage range	CMRR > 70 dB, $R_S = 50\ \Omega$	25°C	0 to 1.4	-0.3 to 1.7		0 to 1.4	-0.3 to 1.7	V	
			Full range	0 to 1.4	-0.3 to 1.7		0 to 1.4	-0.3 to 1.7		
V_{OH}	High-level output voltage	$I_{OH} = -0.675\text{ mA}$	25°C	2.6			2.6			V
			Full range	2.5			2.5			
		$I_{OH} = -2.2\text{ mA}$	25°C	2.4			2.4			
			Full range	2.1			2.1			
V_{OL}	Low-level output voltage	$V_{IC} = 1.35\text{ V},$ $I_{OL} = 0.675\text{ mA}$	25°C	0.1			0.1			V
			Full range	0.2			0.2			
		$V_{IC} = 1.35\text{ V},$ $I_{OL} = 2.2\text{ mA}$	25°C	0.21			0.21			
			Full range	0.6			0.6			
A_{VD}	Large-signal differential voltage amplification	$V_{IC} = 1.35\text{ V},$ $R_L = 10\text{ k}\Omega,$ $V_O = 0.6\text{ V to } 2.1\text{ V}$	25°C	20	380		20	380	V/mV	
			Full range	13			13			
$r_{i(d)}$	Differential input resistance		25°C	10^{12}			10^{12}			Ω
$c_{i(c)}$	Common-mode input capacitance	$f = 10\text{ kHz},$	25°C	8			8			pF
z_o	Closed-loop output impedance	$f = 100\text{ kHz},$ $A_V = 10$	25°C	25			25			Ω
CMRR	Common-mode rejection ratio	$V_{IC} = 0\text{ to } 1.5\text{ V},$ $V_O = 1.5\text{ V},$ $R_S = 50\ \Omega$	25°C	70	84		70	84	dB	
			Full range	70	82		70	82		
k_{SVR}	Supply voltage rejection ratio ($\Delta V_{DD} / \Delta V_{IO}$)	$V_{DD} = 2.7\text{ V to } 5\text{ V},$ $V_{IC} = V_{DD}/2,$ No load	25°C	70	89		70	89	dB	
			Full range	70	84		70	84		
I_{DD}	Supply current (per channel)	$V_O = 1.5\text{ V},$ No load	25°C	1	2		1	2	mA	
			Full range		2			2		
$I_{DD(SHDN)}$	Supply current in shutdown (per channel)		25°C	0.8	1.5		0.8	1.5	μA	
			Full range	1.3	2		1.3	2		

† Full range is -40°C to 125°C.



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electrical characteristics at specified free-air temperature, $V_{DD} = 2.7$ V (unless otherwise noted) (continued)

PARAMETER		TEST CONDITIONS	T_A †	TLV277xI			TLV277xAI			UNIT	
				MIN	TYP	MAX	MIN	TYP	MAX		
$V_{(ON)}$	Turnon voltage level	TLV2770	$A_V = 5$	25°C	1.47			1.47			V
		TLV2773			1.43			1.43			
		TLV2775			1.40			1.4			
$V_{(OFF)}$	Turnoff voltage level	TLV2770	$A_V = 5$	25°C	1.27			1.27			V
		TLV2773			1.21			1.21			
		TLV2775			1.20			1.2			

† Full range is –40°C to 125°C.

operating characteristics at specified free-air temperature, $V_{DD} = 2.7$ V (unless otherwise noted)

PARAMETER		TEST CONDITIONS		T_A †	TLV277xI			TLV277xAI			UNIT	
					MIN	TYP	MAX	MIN	TYP	MAX		
SR	Slew rate at unity gain	$V_{O(PP)} = 0.8$ V, $C_L = 100$ pF, $R_L = 10$ k Ω		25°C	5	9		5	9		V/ μ s	
				Full range	4.7	6		4.7	6			
V_n	Equivalent input noise voltage	$f = 1$ kHz		25°C	21			21			nV/ $\sqrt{\text{Hz}}$	
				25°C	17			17				
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	$f = 0.1$ Hz to 1 Hz		25°C	0.33			0.33			μ V	
		$f = 0.1$ Hz to 10 Hz		25°C	0.86			0.86			μ V	
I_n	Equivalent input noise current	$f = 100$ Hz		25°C	0.6			0.6			fA/ $\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise	$R_L = 600$ Ω , $f = 1$ kHz		25°C	$A_V = 1$			0.0085%				
					$A_V = 10$			0.025%				
					$A_V = 100$			0.12%				
Gain-bandwidth product		$f = 10$ kHz, $C_L = 100$ pF	$R_L = 600$ Ω ,	25°C	4.8			4.8			MHz	
t_s	Settling time	$A_V = -1$, Step = 0.85 V to 1.85 V, $R_L = 600$ Ω , $C_L = 100$ pF		0.1%	25°C	0.186			0.186			μ s
				0.01%	25°C	3.92			3.92			
ϕ_m	Phase margin at unity gain	$R_L = 600$ Ω , $C_L = 100$ pF		25°C	46°			46°				
	Gain margin			25°C	12			12			dB	

† Full range is –40°C to 125°C.

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PARAMETER		TEST CONDITIONS	T_A †	TLV277xI			TLV277xAI			UNIT	
				MIN	TYP	MAX	MIN	TYP	MAX		
V_{IO}	Input offset voltage	$V_{IC} = 0,$ $V_O = 0,$ $R_S = 50\ \Omega,$ $V_{DD} = \pm 2.5\text{ V}$	25°C	0.36	2.5		0.36	1.6	mV		
			Full range		0.4	2.7		0.4		1.9	
	25°C		0.7	2.5		0.7	2.1				
	Full range		0.78	2.7		0.78	2.2				
α_{VIO}	Temperature coefficient of input offset voltage		25°C to 125°C	2			2			$\mu\text{V}/^\circ\text{C}$	
I_{IO}	Input offset current	$V_{IC} = 0,$ $V_O = 0,$ $R_S = 50\ \Omega,$ $V_{DD} = \pm 2.5\text{ V}$	25°C	1	60		1	60	pA		
			Full range	2	125		2	125			
I_{IB}	Input bias current		25°C	2	60		2	60	pA		
			Full range	6	350		6	350			
V_{ICR}	Common-mode input voltage range	CMRR > 60 dB, $R_S = 50\ \Omega$	25°C	0 to 3.7	-0.3 to 3.8		0 to 3.7	-0.3 to 3.8	V		
			Full range	0 to 3.7	-0.3 to 3.8		0 to 3.7	-0.3 to 3.8			
V_{OH}	High-level output voltage		$I_{OH} = -1.3\text{ mA}$	25°C	4.9			4.9			V
				Full range	4.8			4.8			
		$I_{OH} = -4.2\text{ mA}$	25°C	4.7			4.7				
			Full range	4.4			4.4				
V_{OL}	Low-level output voltage	$V_{IC} = 2.5\text{ V},$ $I_{OL} = 1.3\text{ mA}$	25°C	0.1			0.1			V	
			Full range	0.2			0.2				
		$V_{IC} = 2.5\text{ V},$ $I_{OL} = 4.2\text{ mA}$	25°C	0.21			0.21				
			Full range	0.6			0.6				
A_{VD}	Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V},$ $R_L = 10\text{ k}\Omega,$ $V_O = 1\text{ V to }4\text{ V}$	25°C	20	450		20	450	V/mV		
			Full range	13			13				
$r_i(d)$	Differential input resistance			25°C	10^{12}			10^{12}			Ω
$c_i(c)$	Common-mode input capacitance		$f = 10\text{ kHz}$	25°C	8			8			pF
z_o	Closed-loop output impedance	$f = 100\text{ kHz},$ $A_V = 10$	25°C	20			20			Ω	
CMRR	Common-mode rejection ratio	$V_{IC} = 0\text{ to }3.7\text{ V},$ $V_O = 3.7\text{ V},$ $R_S = 50\ \Omega$	25°C	60	96		60	96	dB		
			Full range	60	93		60	93			
k_{SVR}	Supply voltage rejection ratio ($\Delta V_{DD} / \Delta V_{IO}$)		25°C	70	89		70	89	dB		
			Full range	70	84		70	84			
I_{DD}	Supply current (per channel)	$V_O = 1.5\text{ V},$ No load	25°C	1	2		1	2	mA		
			Full range		2			2			
$I_{DD}(SHDN)$	Supply current shutdown (per channel)		25°C	0.8	1.5		0.8	1.5	μA		
			Full range	1.3	2		1.3	2			

† Full range is -40°C to 125°C .



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PARAMETER		TEST CONDITIONS	T_A †	TLV277xI			TLV277xAI			UNIT	
				MIN	TYP	MAX	MIN	TYP	MAX		
$V_{(ON)}$	Turnon voltage level	TLV2770	$A_V = 5$	25°C	2.59			2.59			V
		TLV2773			2.47			2.47			
		TLV2775			2.48			2.48			
$V_{(OFF)}$	Turnoff voltage level	TLV2770	$A_V = 5$	25°C	2.41			2.41			V
		TLV2773			2.32			2.32			
		TLV2775			2.29			2.29			

† Full range is -40°C to 125°C .

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

PARAMETER		TEST CONDITIONS		T_A †	TLV277xI			TLV277xAI			UNIT	
					MIN	TYP	MAX	MIN	TYP	MAX		
SR	Slew rate at unity gain	$V_{O(PP)} = 1.5\text{ V}$, $C_L = 100\text{ pF}$, $R_L = 10\text{ k}\Omega$		25°C	5	10.5		5	10.5		$\text{V}/\mu\text{s}$	
				Full range	4.7	6		4.7	6			
V_n	Equivalent input noise voltage	$f = 1\text{ kHz}$		25°C	17			17			$\text{nV}/\sqrt{\text{Hz}}$	
				25°C	12			12				
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ Hz to }1\text{ Hz}$		25°C	0.33			0.33			μV	
		$f = 0.1\text{ Hz to }10\text{ Hz}$		25°C	0.86			0.86			μV	
I_n	Equivalent input noise current	$f = 100\text{ Hz}$		25°C	0.6			0.6			$\text{fA}/\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise	$R_L = 600\ \Omega$, $f = 1\text{ kHz}$		25°C	$A_V = 1$			0.005%				
					$A_V = 10$			0.016%				
					$A_V = 100$			0.095%				
Gain-bandwidth product		$f = 10\text{ kHz}$, $C_L = 100\text{ pF}$	$R_L = 600\ \Omega$	25°C	5.1			5.1			MHz	
t_s	Settling time	$A_V = -1$, Step = 1.5 V to 3.5 V , $R_L = 600\ \Omega$, $C_L = 100\text{ pF}$		0.1%	25°C	0.134			0.134			μs
				0.01%	25°C	1.97			1.97			
ϕ_m	Phase margin at unity gain	$R_L = 600\ \Omega$, $C_L = 100\text{ pF}$		25°C	46°			46°				
	Gain margin			25°C	12			12			dB	
$t_{(ON)}$	Amplifier turnon time	TLV2770	$A_V = 5$, $R_L = \text{Open}$, Measured to 50% point	25°C	1.2			1.2			μs	
		TLV2773			2.4			2.4				
		TLV2775			1.9			1.9				
$t_{(OFF)}$	Amplifier turnoff time	TLV2770	$A_V = 5$, $R_L = \text{Open}$, Measured to 50% point	25°C	335			335			ns	
		TLV2773			444			444				
		TLV2775			345			345				

† Full range is -40°C to 125°C .

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PARAMETER	TEST CONDITIONS	T_A †	TLV2772Q TLV2772M			TLV2772AQ TLV2772AM			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO} Input offset voltage	$V_{DD} = \pm 1.35\text{ V}$, $V_{IC} = 0$, $R_S = 50\ \Omega$	25°C	0.44	2.5		0.44	1.6	mV	
		Full range	0.47	2.7		0.47	1.9		
α_{VIO} Temperature coefficient of input offset voltage		25°C to 125°C	2			2			$\mu\text{V}/^\circ\text{C}$
		I_{IO} Input offset current	25°C	1	60		1	60	pA
Full range			2	125		2	125		
I_{IB} Input bias current		25°C	2	60		2	60	pA	
	Full range	6	350		6	350			
V_{ICR} Common-mode input voltage range	CMRR > 60 dB, $R_S = 50\ \Omega$	25°C	0 to 1.4	-0.3 to 1.7		0 to 1.4	-0.3 to 1.7	V	
		Full range	0 to 1.4	-0.3 to 1.7		0 to 1.4	-0.3 to 1.7		
V_{OH} High-level output voltage	$I_{OH} = -0.675\text{ mA}$	25°C	2.6			2.6			V
		Full range	2.45			2.45			
	$I_{OH} = -2.2\text{ mA}$	25°C	2.4			2.4			
		Full range	2.1			2.1			
V_{OL} Low-level output voltage	$V_{IC} = 1.35\text{ V}$, $I_{OL} = 0.675\text{ mA}$	25°C	0.1			0.1			V
		Full range	0.2			0.2			
	$V_{IC} = 1.35\text{ V}$, $I_{OL} = 2.2\text{ mA}$	25°C	0.21			0.21			
		Full range	0.6			0.6			
A_{VD} Large-signal differential voltage amplification	$V_{IC} = 1.35\text{ V}$, $V_O = 0.6\text{ V to } 2.1\text{ V}$	$R_L = 10\text{ k}\Omega, \ddagger$	25°C	20	380		20	380	V/mV
			Full range	13			13		
$r_{i(d)}$ Differential input resistance		25°C	1012			1012			Ω
$C_{i(c)}$ Common-mode input capacitance	$f = 10\text{ kHz}$,	25°C	8			8			pF
z_o Closed-loop output impedance	$f = 100\text{ kHz}$, $A_V = 10$	25°C	25			25			Ω
CMRR Common-mode rejection ratio	$V_{IC} = V_{ICR}(\text{min})$, $R_S = 50\ \Omega$	$V_O = 1.5\text{ V}$,	25°C	60	84		60	84	dB
			Full range	60	82		60	82	
k_{SVR} Supply voltage rejection ratio ($\Delta V_{DD} / \Delta V_{IO}$)	$V_{DD} = 2.7\text{ V to } 5\text{ V}$, No load	$V_{IC} = V_{DD}/2$,	25°C	70	89		70	89	dB
			Full range	70	84		70	84	
I_{DD} Supply current (per channel)	$V_O = 1.5\text{ V}$, No load	25°C	1	2		1	2	mA	
		Full range		2			2		

† Full range is -40°C to 125°C for Q level part, -55°C to 125°C for M level part.

‡ Referenced to 1.35 V



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PARAMETER	TEST CONDITIONS	T_A †	TLV2772Q TLV2772M			TLV2772AQ TLV2772AM			UNIT		
			MIN	TYP	MAX	MIN	TYP	MAX			
SR	Slew rate at unity gain	$V_{O(PP)} = 0.8\text{ V}$, $C_L = 100\text{ pF}$, $R_L = 10\text{ k}\Omega$	25°C	5	9		5	9	$\text{V}/\mu\text{s}$		
			Full range	4.7	6		4.7	6			
V_n	Equivalent input noise voltage	$f = 1\text{ kHz}$	25°C	21			21			$\text{nV}/\sqrt{\text{Hz}}$	
			$f = 10\text{ kHz}$	17			17				
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ Hz to }1\text{ Hz}$	25°C	0.33			0.33			μV	
			$f = 0.1\text{ Hz to }10\text{ Hz}$	0.86			0.86			μV	
I_n	Equivalent input noise current	$f = 100\text{ Hz}$	25°C	0.6			0.6			$\text{fA}/\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise	$R_L = 600\ \Omega$, $f = 1\text{ kHz}$	25°C	$A_V = 1$	0.0085%			0.0085%			
				$A_V = 10$	0.025%			0.025%			
				$A_V = 100$	0.12%			0.12%			
Gain-bandwidth product		$f = 10\text{ kHz}$, $C_L = 100\text{ pF}$	$R_L = 600\ \Omega$, 25°C	4.8			4.8			MHz	
t_s	Settling time	$A_V = -1$, Step = 0.85 V to 1.85 V, $R_L = 600\ \Omega$, $C_L = 100\text{ pF}$	0.1%	25°C	0.186			0.186			μs
			0.01%	25°C	3.92			3.92			
ϕ_m	Phase margin at unity gain	$R_L = 600\ \Omega$, $C_L = 100\text{ pF}$	25°C	46°			46°				
	Gain margin		25°C	12			12				dB

† Full range is -40°C to 125°C for Q level part, -55°C to 125°C for M level part.

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PARAMETER	TEST CONDITIONS	T_A †	TLV2772Q TLV2772M			TLV2772AQ TLV2772AM			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO} Input offset voltage	$V_{DD} = \pm 2.5\text{ V}$, $V_{IC} = 0$, $V_O = 0$, $R_S = 50\ \Omega$	25°C	0.36	2.5		0.36	1.6	mV	
		Full range		0.4	2.7		0.4		1.9
α_{VIO} Temperature coefficient of input offset voltage		25°C to 125°C		2			2	$\mu\text{V}/^\circ\text{C}$	
I_{IO} Input offset current		25°C		1	60		1	60	pA
		Full range		2	125		2	125	
I_{IB} Input bias current		25°C		2	60		2	60	pA
	Full range		6	350		6	350		
V_{ICR} Common-mode input voltage range	CMRR > 60 dB, $R_S = 50\ \Omega$	25°C	0 to 3.7	-0.3 to 3.8		0 to 3.7	-0.3 to 3.8	V	
		Full range		0 to 3.7	-0.3 to 3.8		0 to 3.7		-0.3 to 3.8
V_{OH} High-level output voltage	$I_{OH} = -1.3\text{ mA}$	25°C		4.9		4.9	V		
		Full range		4.8		4.8			
	$I_{OH} = -4.2\text{ mA}$	25°C		4.7		4.7			
		Full range		4.4		4.4			
V_{OL} Low-level output voltage	$V_{IC} = 2.5\text{ V}$, $I_{OL} = 1.3\text{ mA}$	25°C		0.1		0.1	V		
		Full range			0.2			0.2	
	$V_{IC} = 2.5\text{ V}$, $I_{OL} = 4.2\text{ mA}$	25°C		0.21		0.21			
		Full range			0.6			0.6	
A_{VD} Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$, $V_O = 1\text{ V to }4\text{ V}$	$R_L = 10\text{ k}\Omega, \ddagger$	25°C	20	450	20	450	V/mV	
			Full range	13		13			
$r_{i(d)}$ Differential input resistance		25°C		1012		1012	Ω		
$C_{i(c)}$ Common-mode input capacitance	$f = 10\text{ kHz}$,	25°C		8		8	pF		
z_o Closed-loop output impedance	$f = 100\text{ kHz}$, $A_V = 10$	25°C		20		20	Ω		
CMRR Common-mode rejection ratio	$V_{IC} = V_{ICR}(\text{min})$, $R_S = 50\ \Omega$	$V_O = 3.7\text{ V}$,	25°C	60	96	60	96	dB	
			Full range	60	93	60	93		
k_{SVR} Supply voltage rejection ratio ($\Delta V_{DD} / \Delta V_{IO}$)	$V_{DD} = 2.7\text{ V to }5\text{ V}$, No load	$V_{IC} = V_{DD}/2$,	25°C	70	89	70	89	dB	
			Full range	70	84	70	84		
I_{DD} Supply current (per channel)	$V_O = 1.5\text{ V}$, No load	25°C		1	2		1	mA	
		Full range			2		2		

† Full range is -40°C to 125°C for Q level part, -55°C to 125°C for M level part.

‡ Referenced to 2.5 V



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

PARAMETER	TEST CONDITIONS	T_A †	TLV2772Q TLV2772M			TLV2772AQ TLV2772AM			UNIT		
			MIN	TYP	MAX	MIN	TYP	MAX			
SR	Slew rate at unity gain	$V_{O(PP)} = 1.5\text{ V}$, $C_L = 100\text{ pF}$, $R_L = 10\text{ k}\Omega$	25°C	5	10.5		5	10.5	$\text{V}/\mu\text{s}$		
			Full range	4.7	6		4.7	6			
V_n	Equivalent input noise voltage	$f = 1\text{ kHz}$	25°C	17			17			$\text{nV}/\sqrt{\text{Hz}}$	
			$f = 10\text{ kHz}$	12			12				
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ Hz to }1\text{ Hz}$	25°C	0.33			0.33			μV	
			$f = 0.1\text{ Hz to }10\text{ Hz}$	0.86			0.86			μV	
I_n	Equivalent input noise current	$f = 100\text{ Hz}$	25°C	0.6			0.6			$\text{fA}/\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise	$R_L = 600\ \Omega$, $f = 1\text{ kHz}$	25°C	$A_V = 1$	0.005%			0.005%			
				$A_V = 10$	0.016%			0.016%			
				$A_V = 100$	0.095%			0.095%			
Gain-bandwidth product		$f = 10\text{ kHz}$, $C_L = 100\text{ pF}$	$R_L = 600\ \Omega$, 25°C	5.1			5.1			MHz	
t_s	Settling time	$A_V = -1$, Step = 1.5 V to 3.5 V, $R_L = 600\ \Omega$, $C_L = 100\text{ pF}$	0.1%	25°C	0.134			0.134			μs
			0.01%	25°C	1.97			1.97			
ϕ_m	Phase margin at unity gain	$R_L = 600\ \Omega$, $C_L = 100\text{ pF}$	25°C	46°			46°				
	Gain margin		25°C	12			12				dB

† Full range is -40°C to 125°C for Q level part, -55°C to 125°C for M level part.

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TYPICAL CHARACTERISTICS

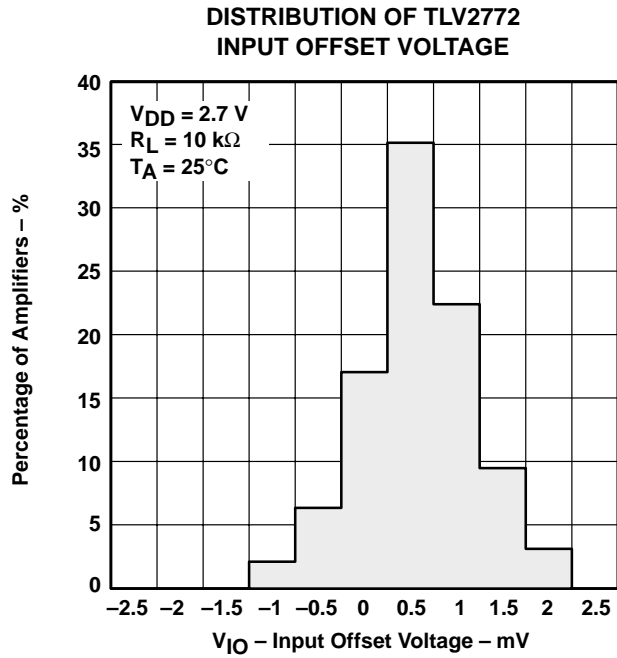


Figure 1

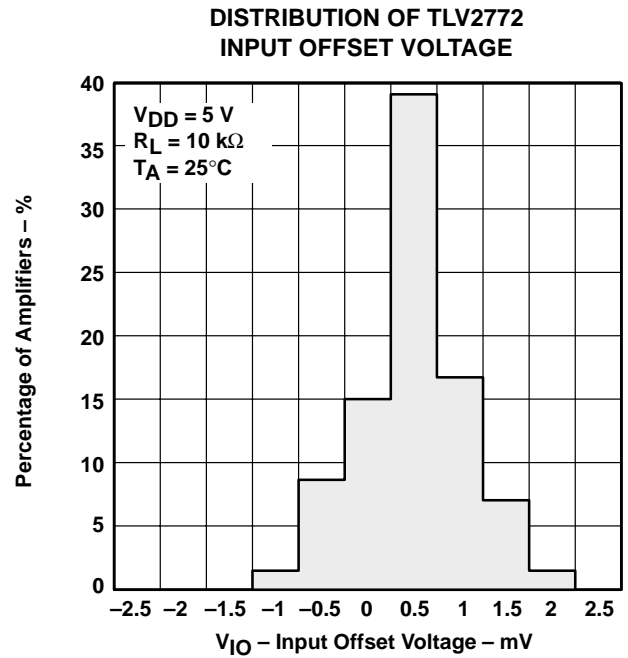


Figure 2

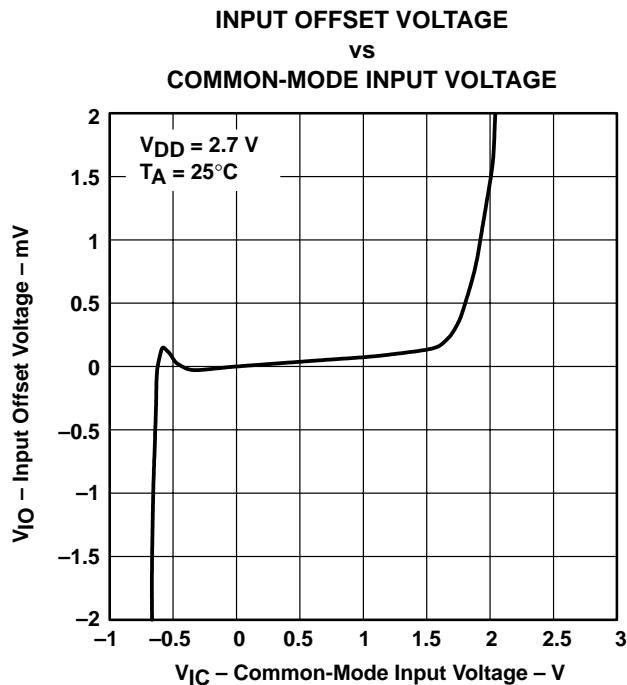


Figure 3

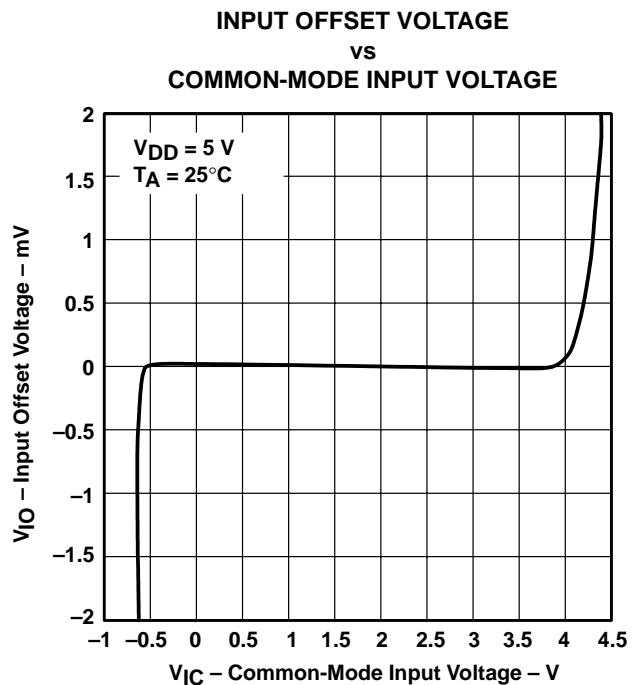


Figure 4

TLV277x, TLV277xA
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DISTRIBUTION OF TLV2772
INPUT OFFSET VOLTAGE

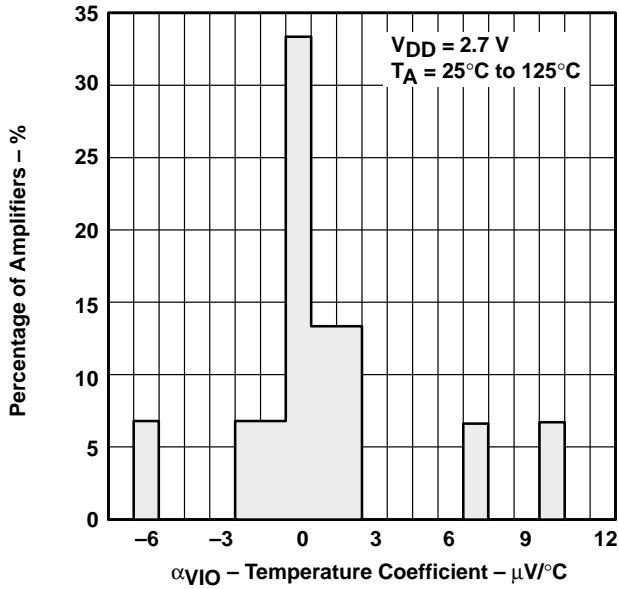


Figure 5

DISTRIBUTION OF TLV2772
INPUT OFFSET VOLTAGE

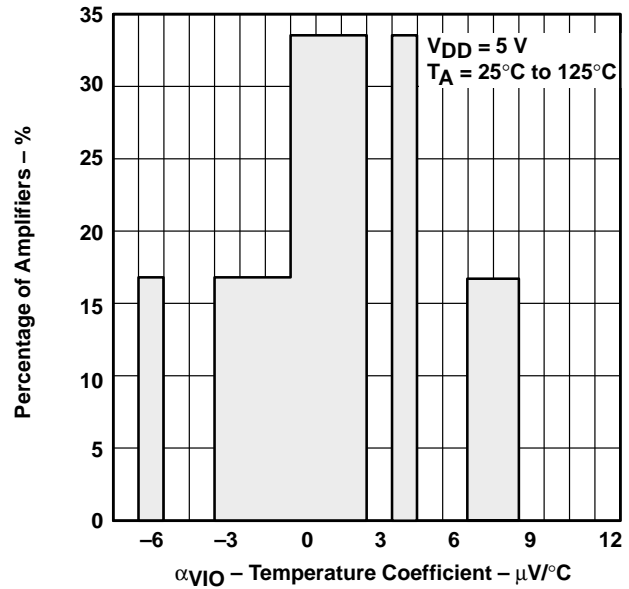


Figure 6

INPUT BIAS AND OFFSET CURRENT
vs
FREE-AIR TEMPERATURE

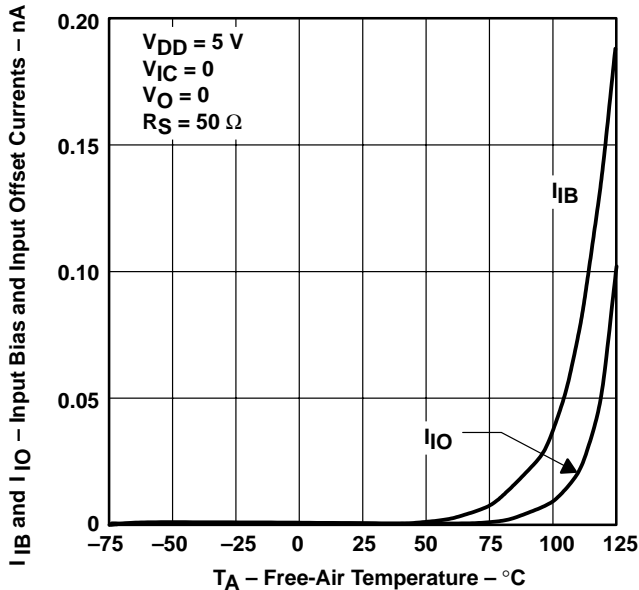


Figure 7

HIGH-LEVEL OUTPUT VOLTAGE
vs
HIGH-LEVEL OUTPUT CURRENT

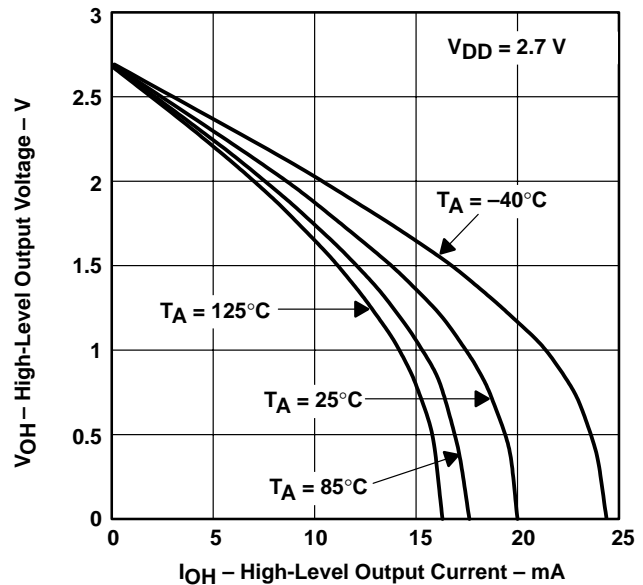


Figure 8



TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
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TYPICAL CHARACTERISTICS

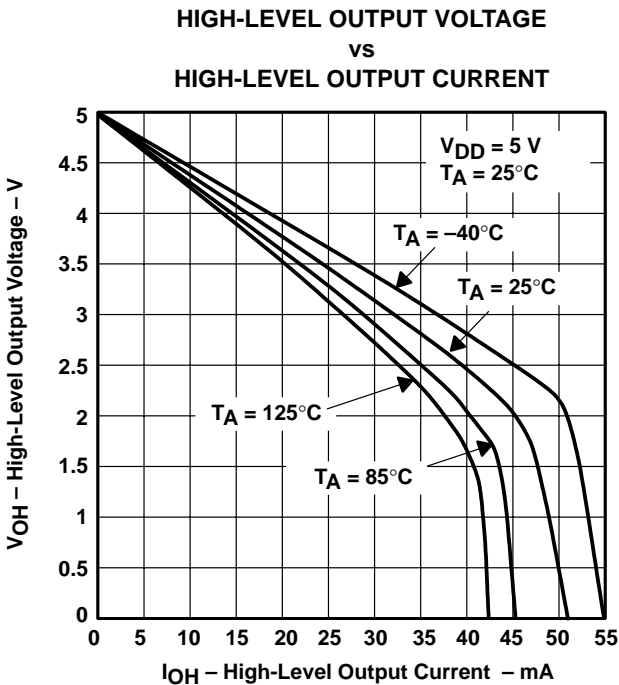


Figure 9

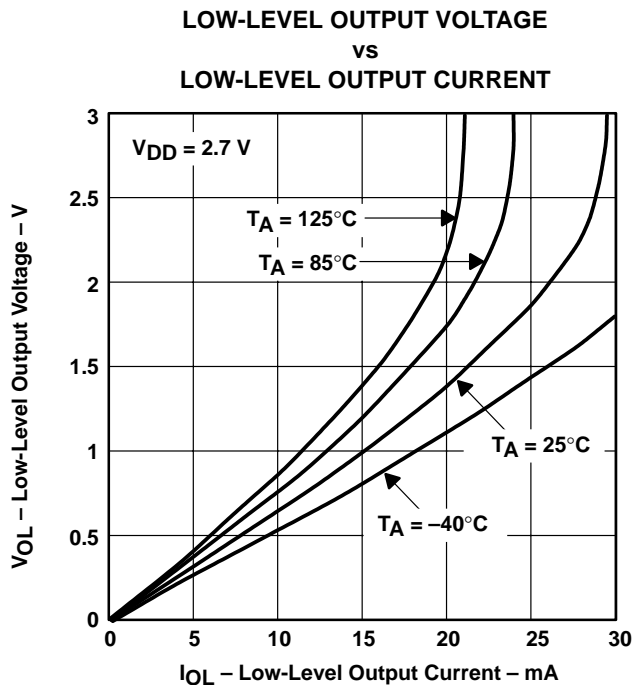


Figure 10

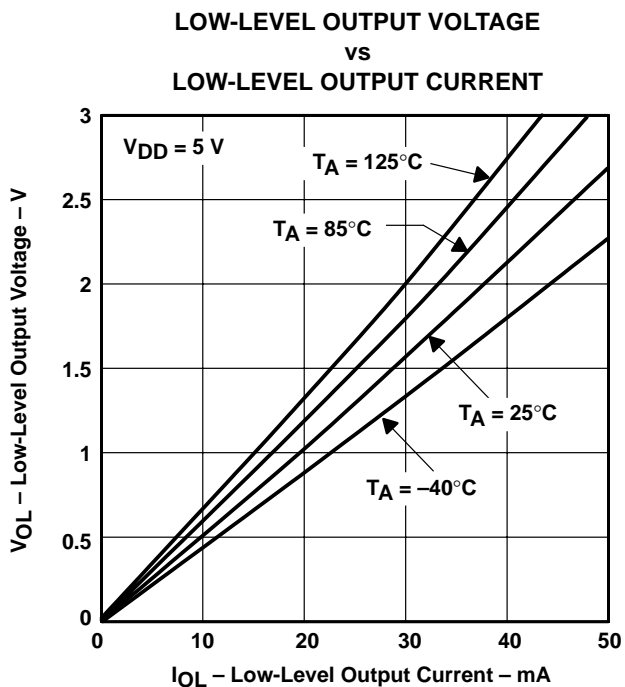


Figure 11

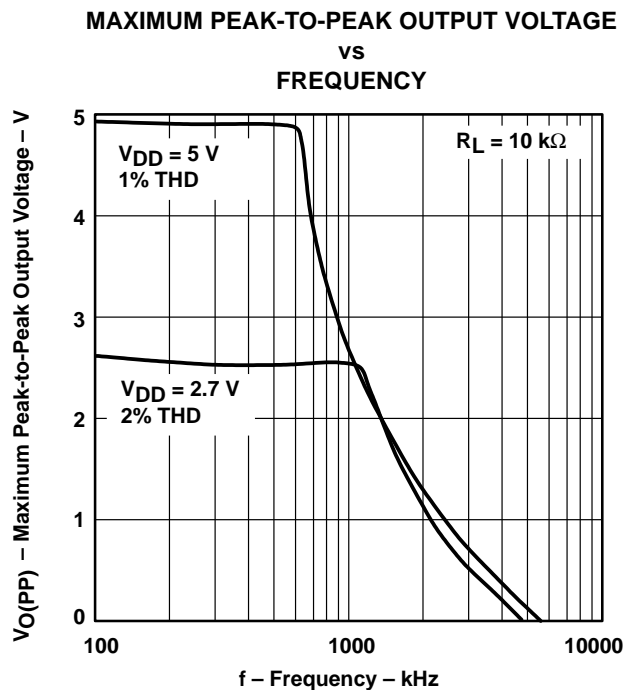


Figure 12

TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

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TYPICAL CHARACTERISTICS

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE
vs
FREQUENCY

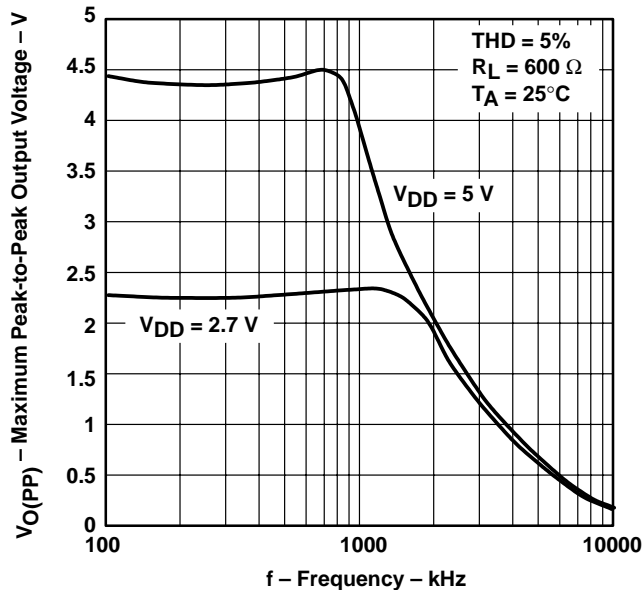


Figure 13

SHORT-CIRCUIT OUTPUT CURRENT
vs
SUPPLY VOLTAGE

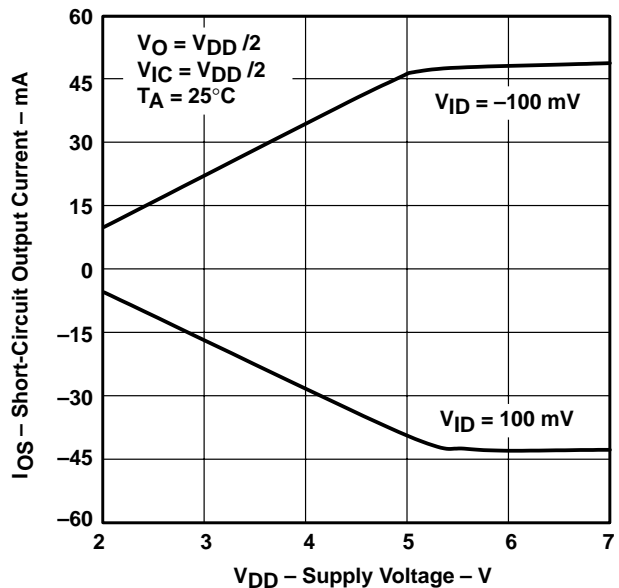


Figure 14

SHORT-CIRCUIT OUTPUT CURRENT
vs
FREE-AIR TEMPERATURE

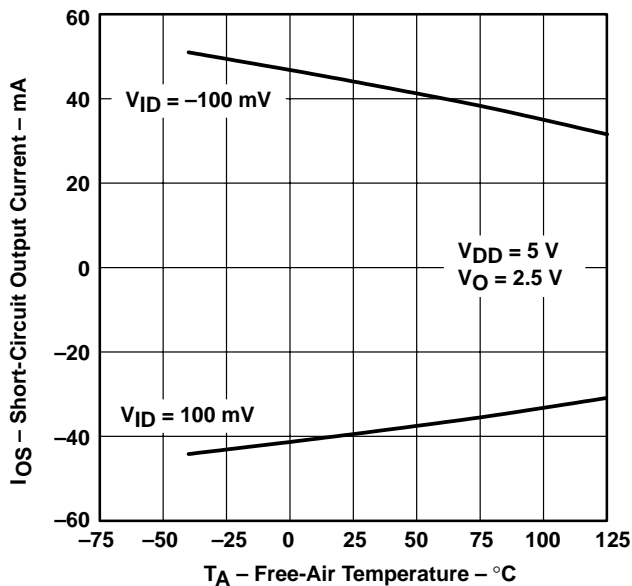


Figure 15

OUTPUT VOLTAGE
vs
DIFFERENTIAL INPUT VOLTAGE

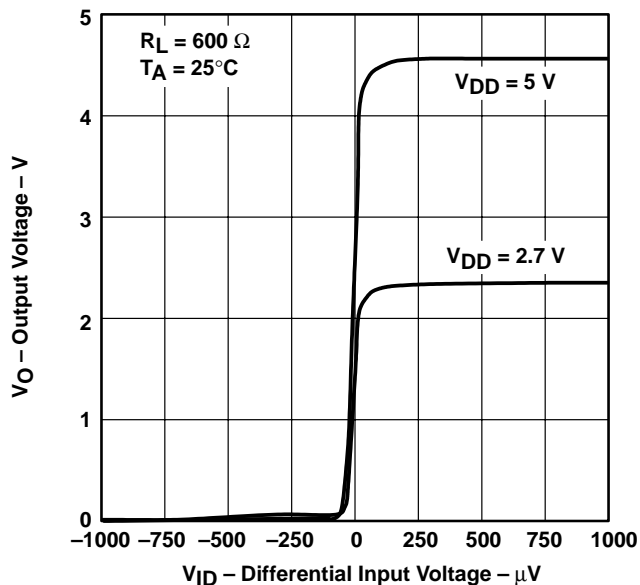


Figure 16

TYPICAL CHARACTERISTICS

**LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION
 AND PHASE MARGIN
 vs
 FREQUENCY**

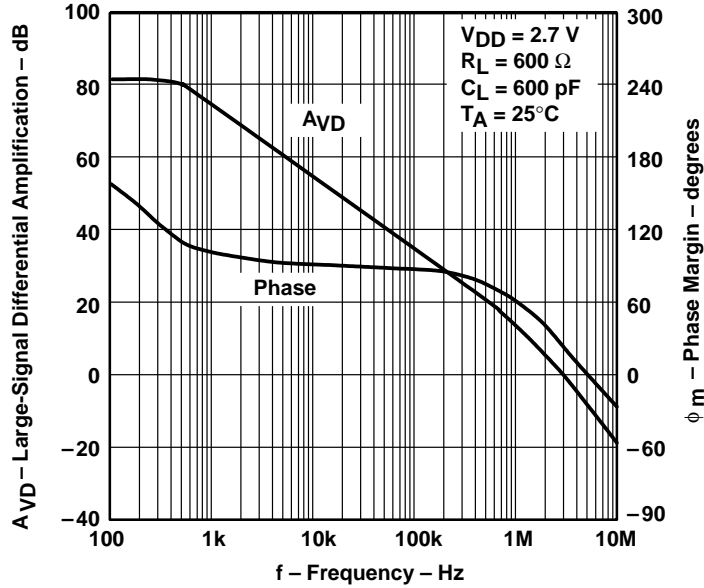


Figure 17

**LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION
 AND PHASE MARGIN
 vs
 FREQUENCY**

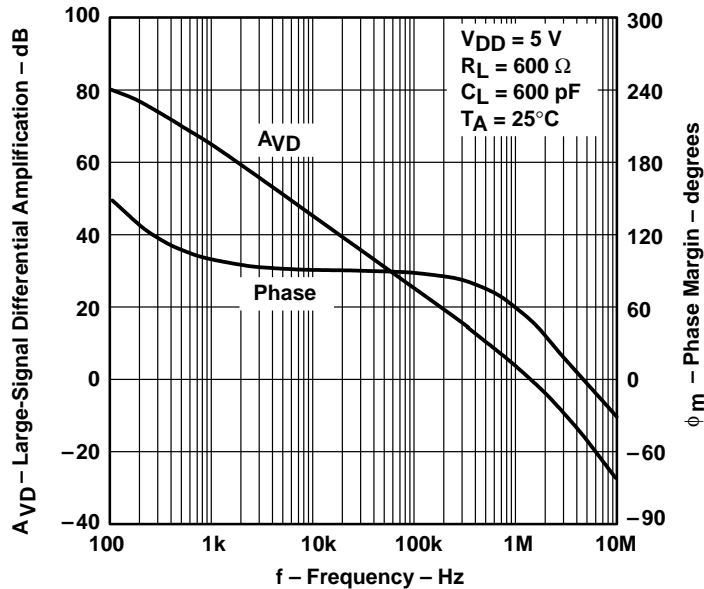


Figure 18

TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

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TYPICAL CHARACTERISTICS

DIFFERENTIAL VOLTAGE AMPLIFICATION
vs
LOAD RESISTANCE

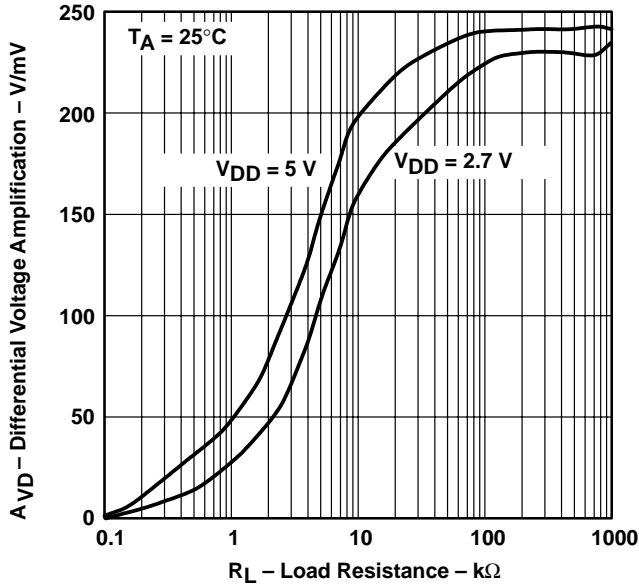


Figure 19

DIFFERENTIAL VOLTAGE AMPLIFICATION
vs
FREE-AIR TEMPERATURE

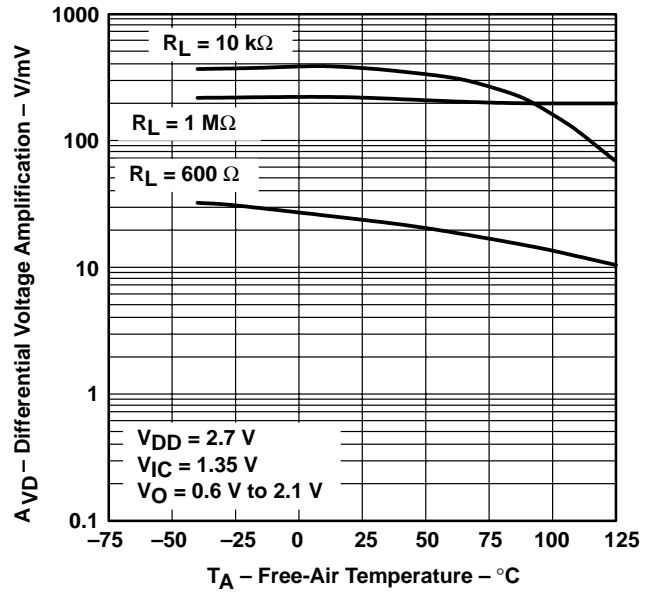


Figure 20

DIFFERENTIAL VOLTAGE AMPLIFICATION
vs
FREE-AIR TEMPERATURE

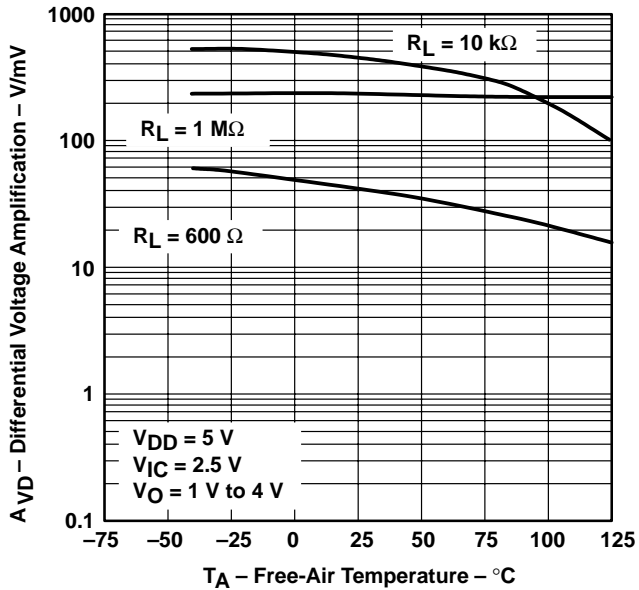


Figure 21

OUTPUT IMPEDANCE
vs
FREQUENCY

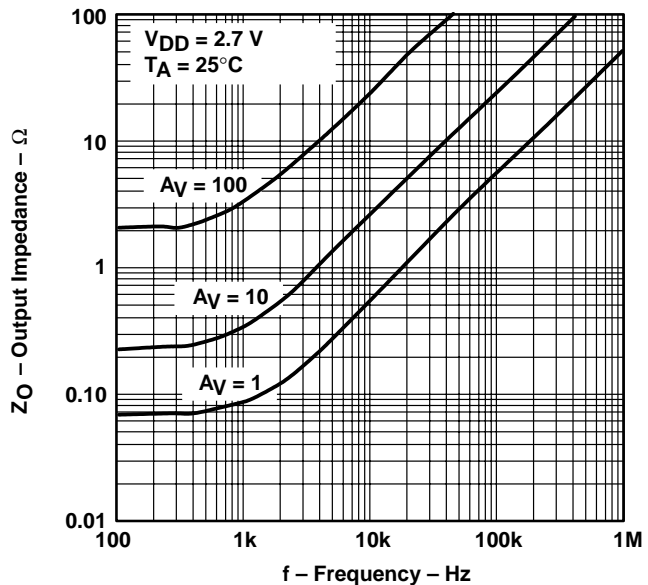


Figure 22



TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

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TYPICAL CHARACTERISTICS

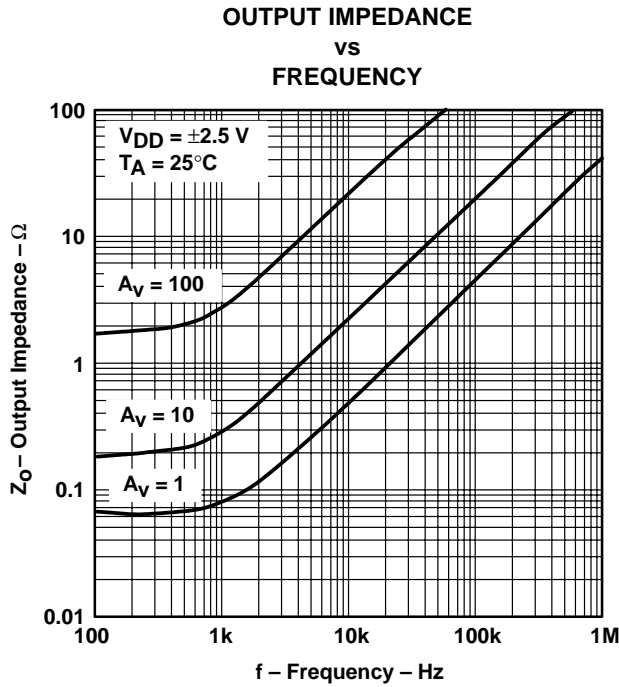


Figure 23

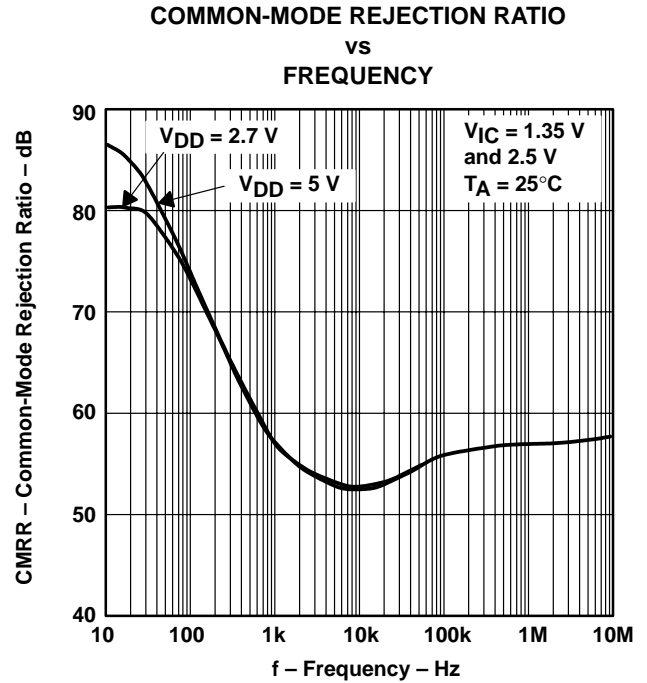


Figure 24

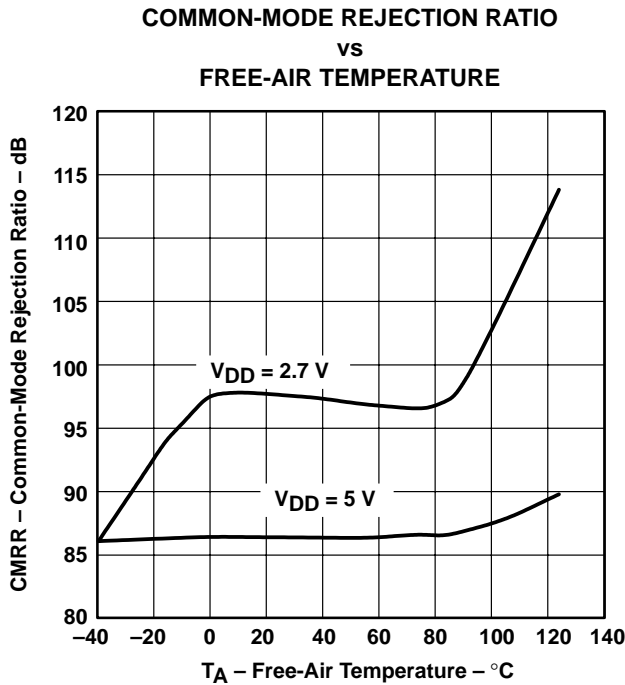


Figure 25

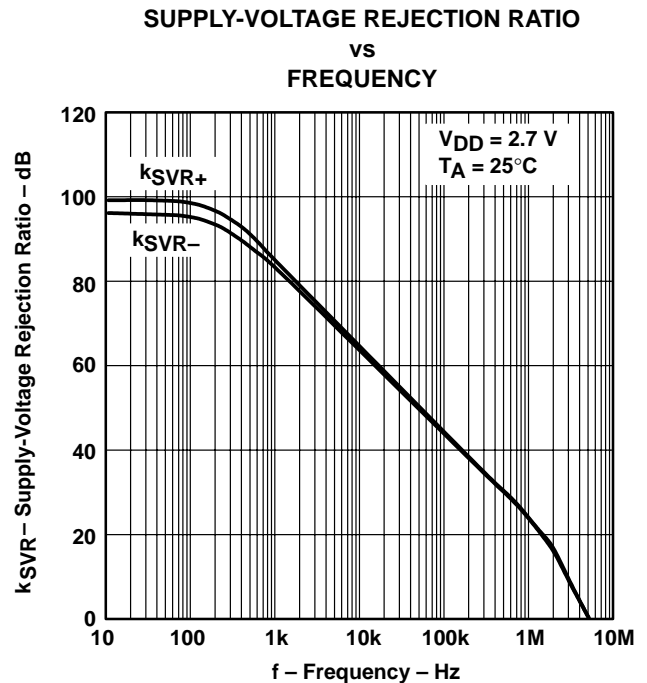


Figure 26



TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
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TYPICAL CHARACTERISTICS

SUPPLY VOLTAGE REJECTION RATIO
vs
FREQUENCY

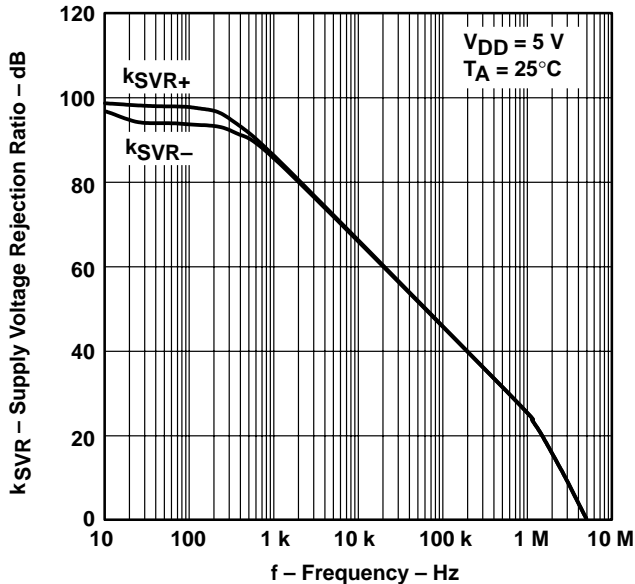


Figure 27

SUPPLY CURRENT (PER CHANNEL)
vs
SUPPLY VOLTAGE

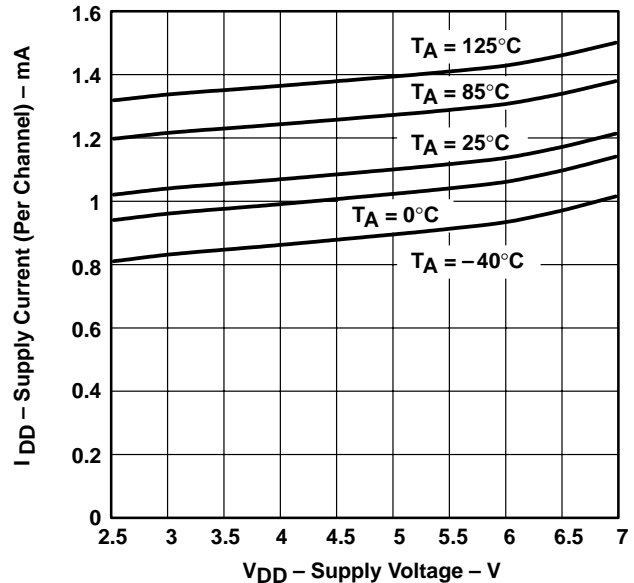


Figure 28

SLEW RATE
vs
LOAD CAPACITANCE

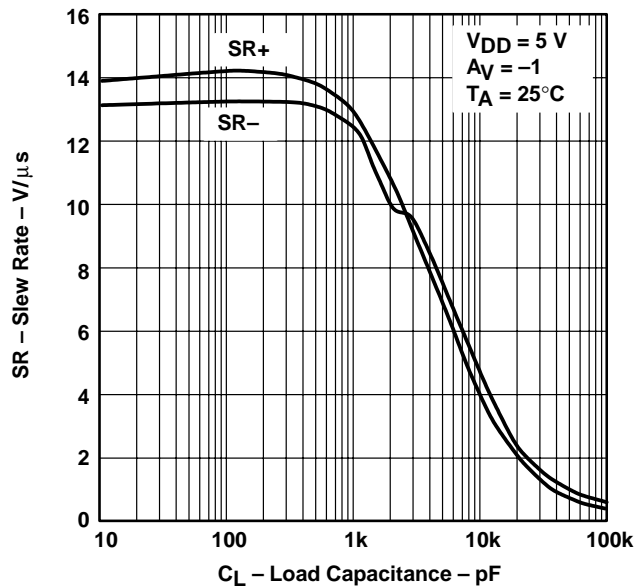


Figure 29

SLEW RATE
vs
FREE-AIR TEMPERATURE

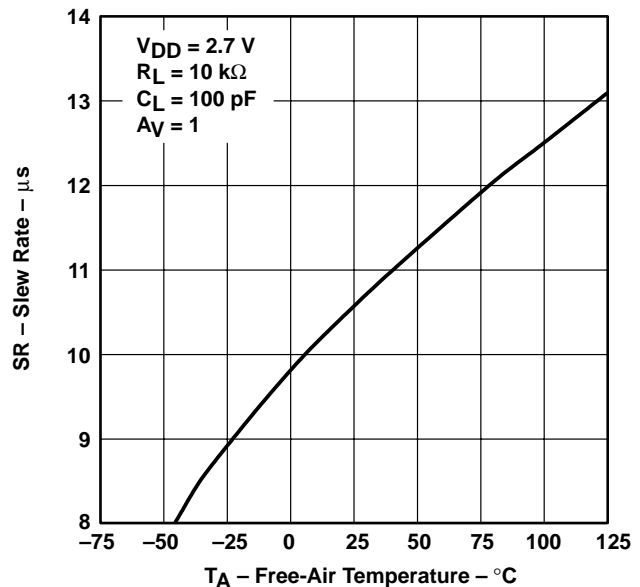
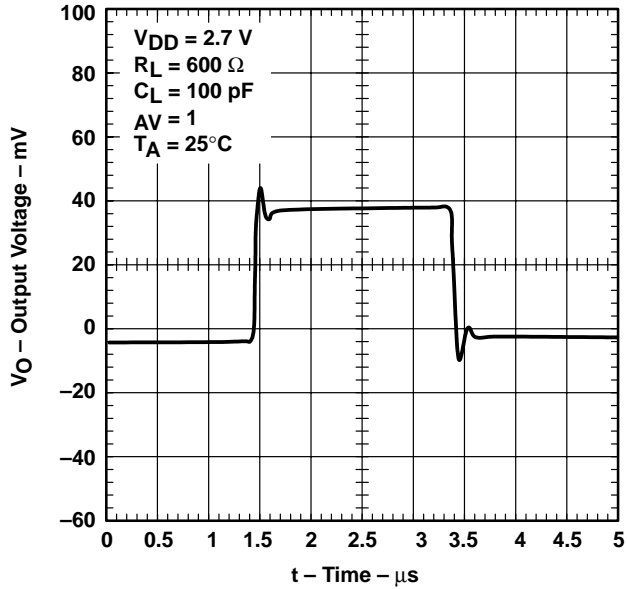


Figure 30

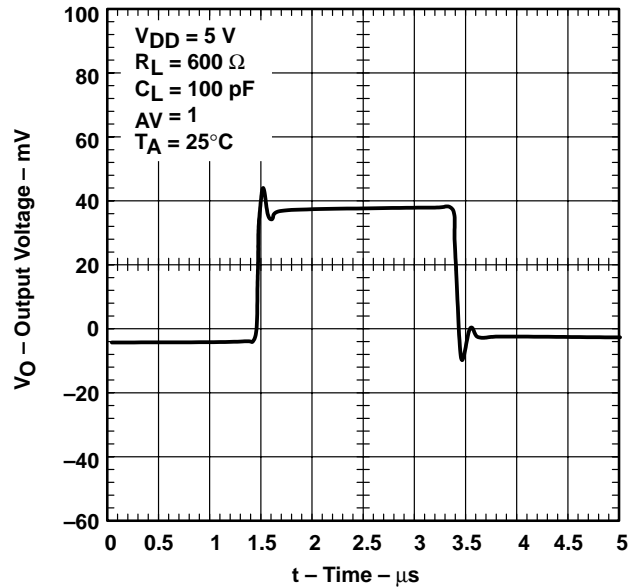


TYPICAL CHARACTERISTICS

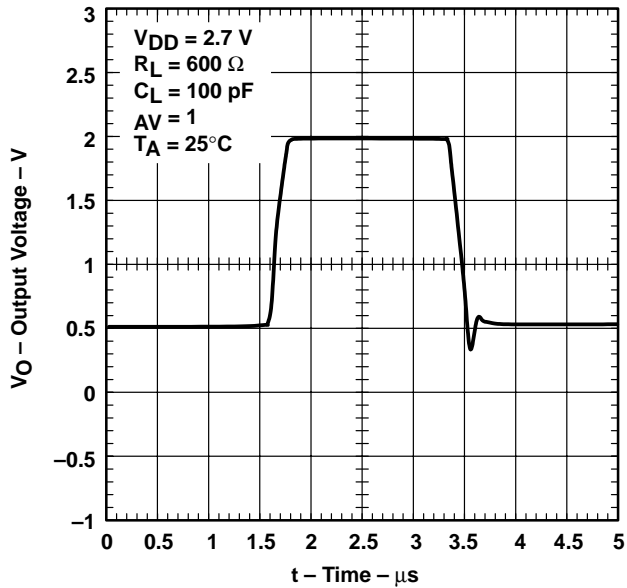
**VOLTAGE-FOLLOWER
 SMALL-SIGNAL PULSE RESPONSE**



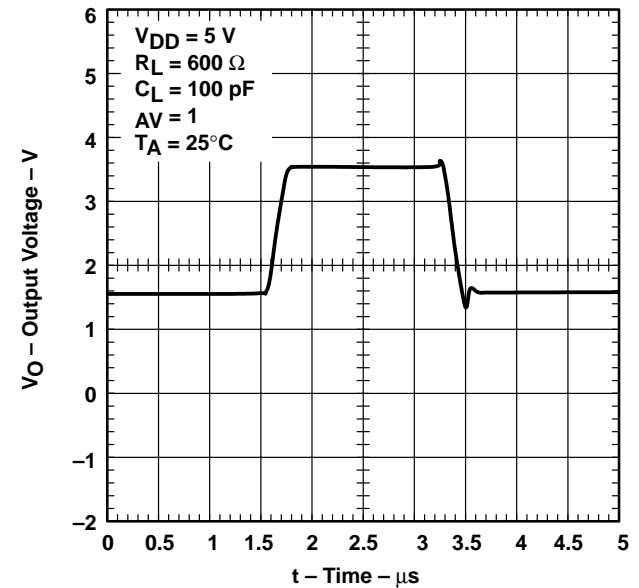
**VOLTAGE-FOLLOWER
 SMALL-SIGNAL PULSE RESPONSE**



**VOLTAGE-FOLLOWER
 LARGE-SIGNAL PULSE RESPONSE**



**VOLTAGE-FOLLOWER
 LARGE-SIGNAL PULSE RESPONSE**



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TYPICAL CHARACTERISTICS

INVERTING SMALL-SIGNAL PULSE RESPONSE

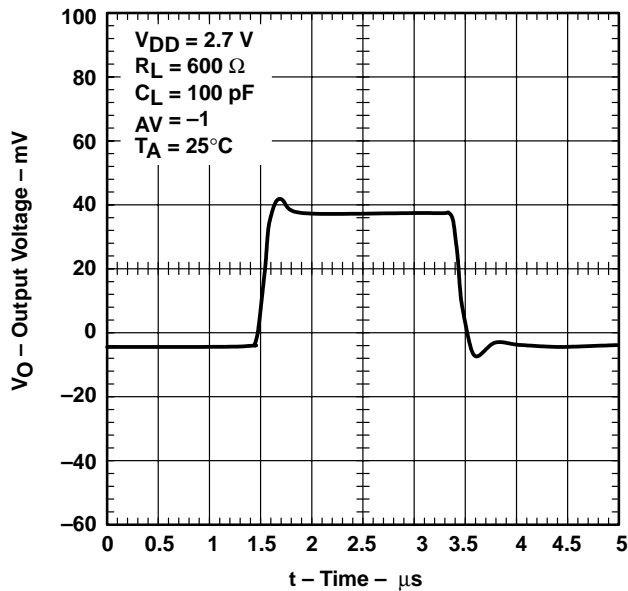


Figure 35

INVERTING SMALL-SIGNAL PULSE RESPONSE

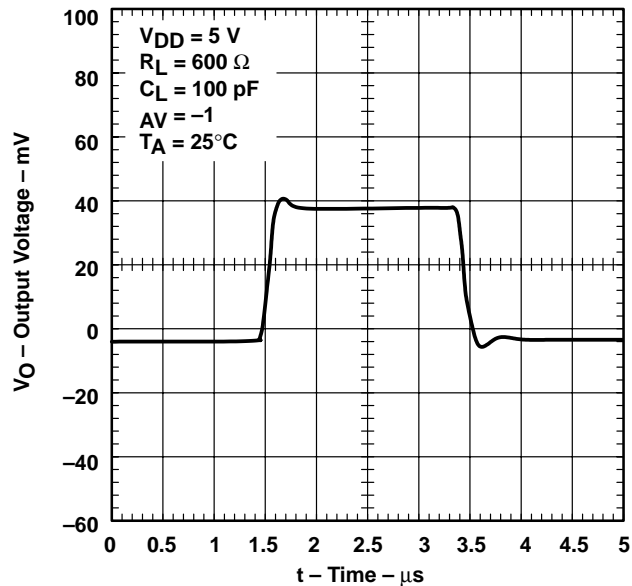


Figure 36

INVERTING LARGE-SIGNAL PULSE RESPONSE

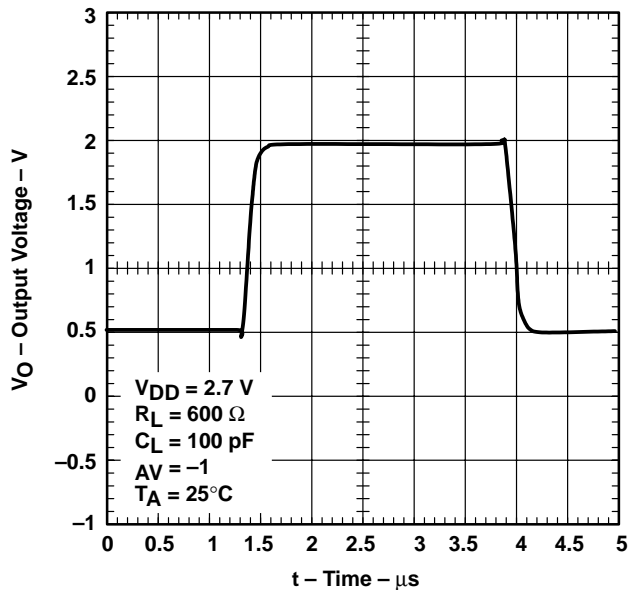


Figure 37

INVERTING LARGE-SIGNAL PULSE RESPONSE

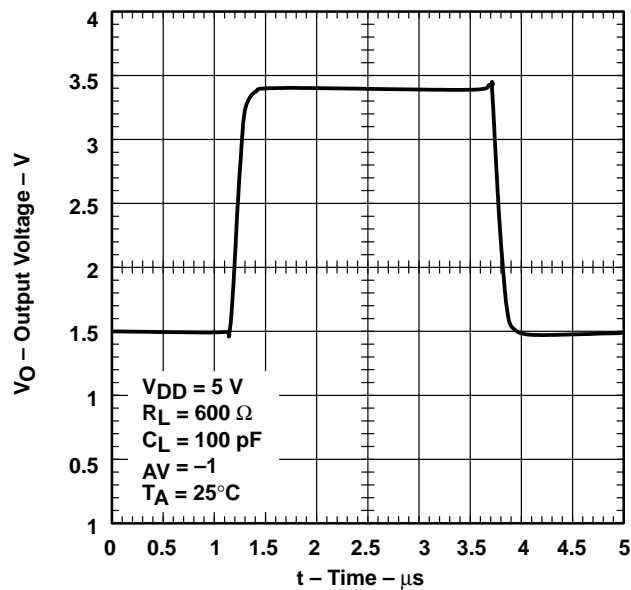


Figure 38

TLV277x, TLV277xA
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TYPICAL CHARACTERISTICS

**EQUIVALENT INPUT NOISE VOLTAGE
 vs
 FREQUENCY**

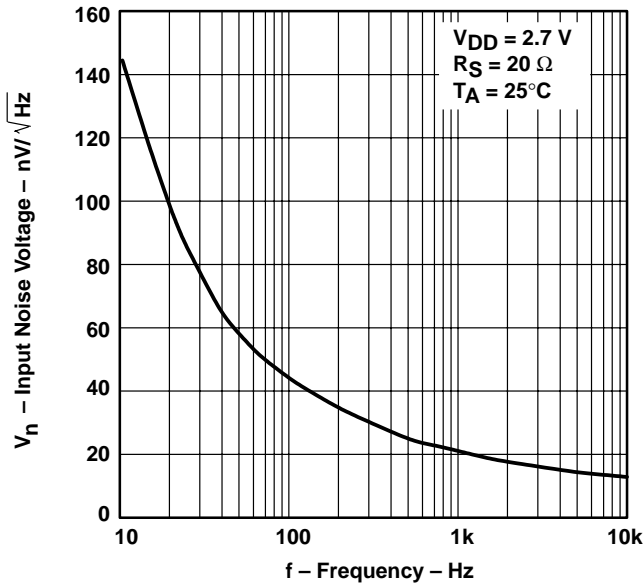


Figure 39

**EQUIVALENT INPUT NOISE VOLTAGE
 vs
 FREQUENCY**

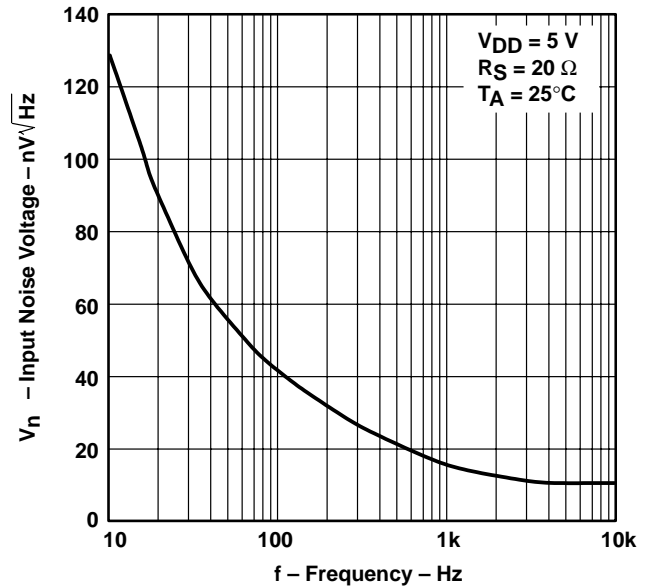


Figure 40

**NOISE VOLTAGE
 OVER A 10 SECOND PERIOD**

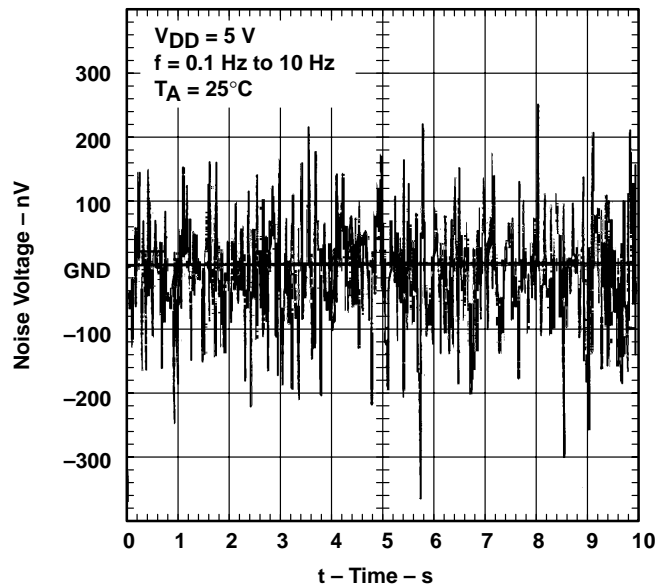


Figure 41

TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
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TYPICAL CHARACTERISTICS

TOTAL HARMONIC DISTORTION PLUS NOISE
vs
FREQUENCY

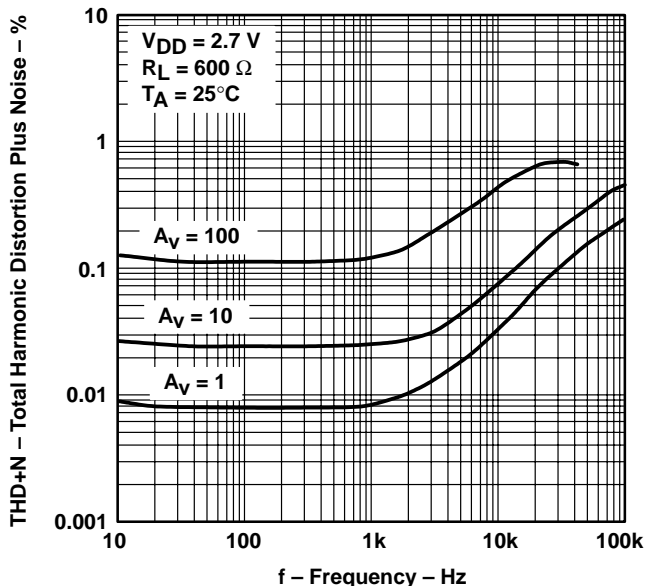


Figure 42

TOTAL HARMONIC DISTORTION PLUS NOISE
vs
FREQUENCY

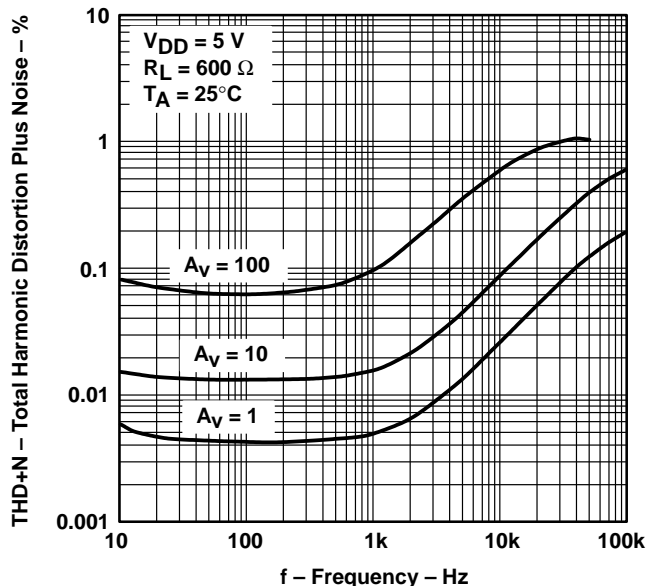


Figure 43

GAIN-BANDWIDTH PRODUCT
vs
SUPPLY VOLTAGE

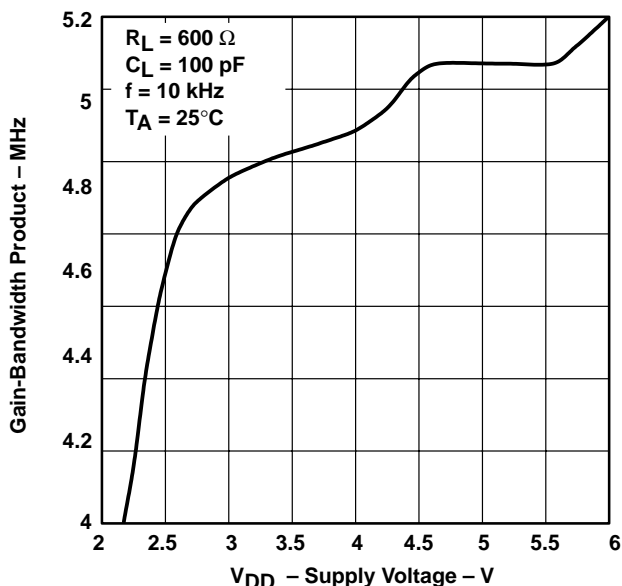


Figure 44

UNITY-GAIN BANDWIDTH
vs
LOAD CAPACITANCE

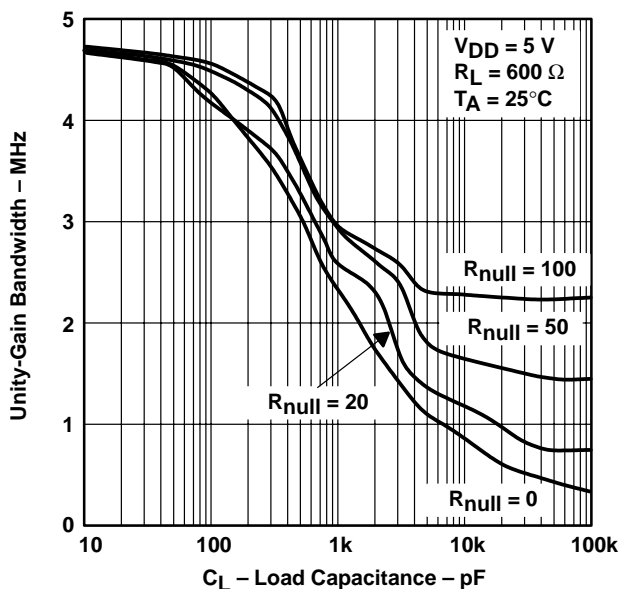


Figure 45



TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
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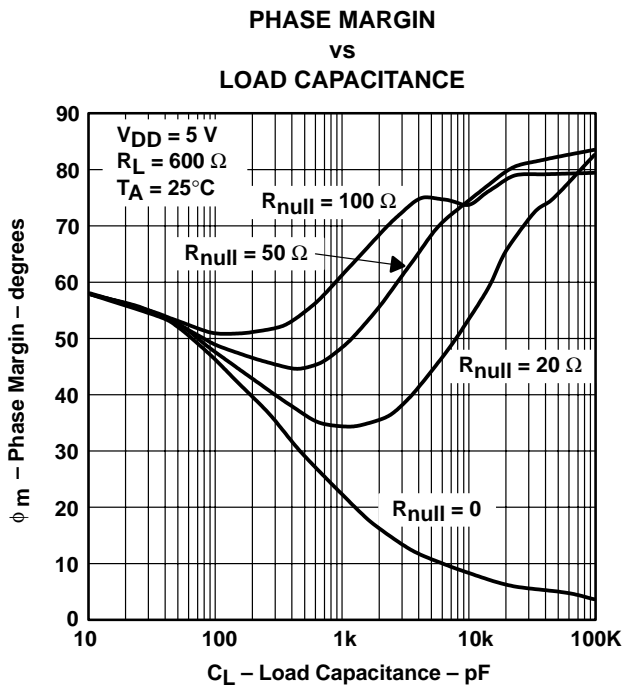


Figure 46

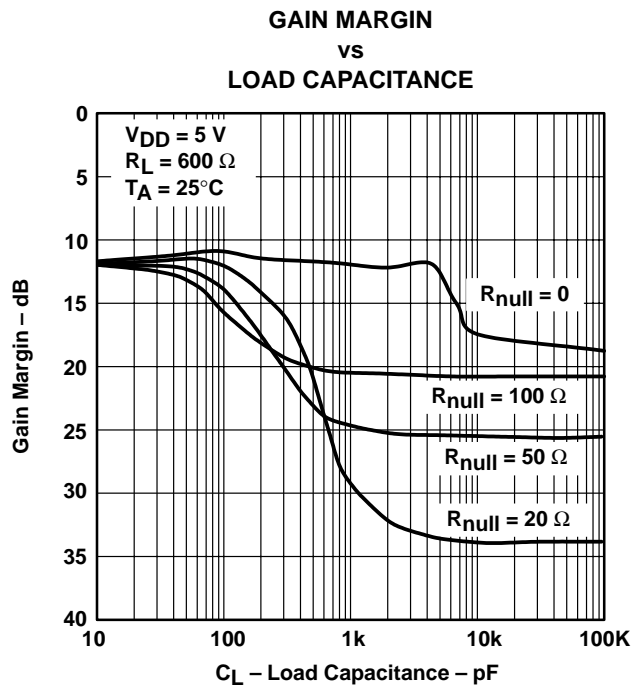


Figure 47

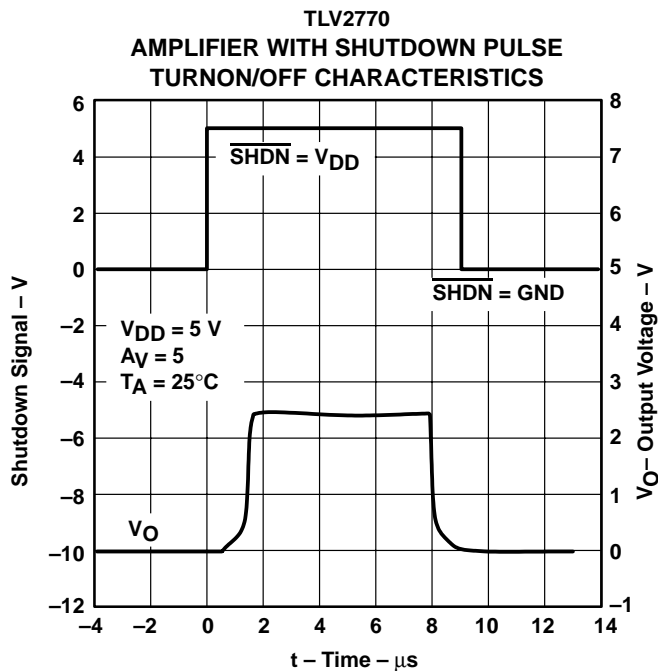


Figure 48

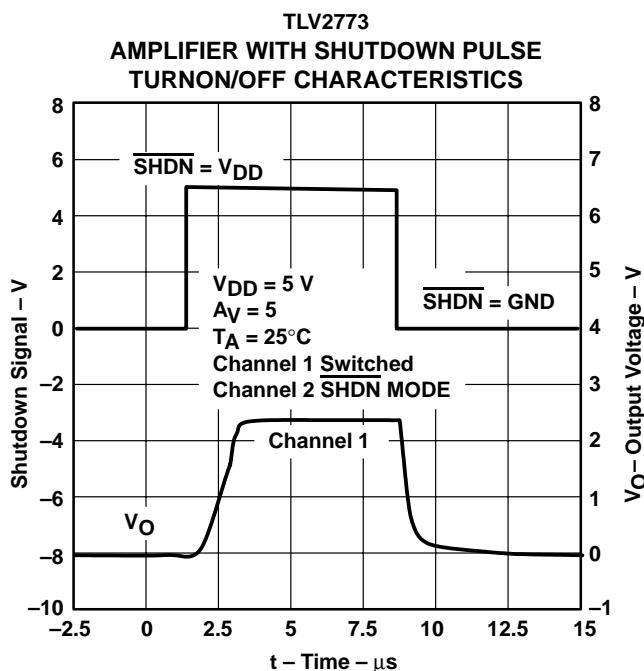


Figure 49

TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
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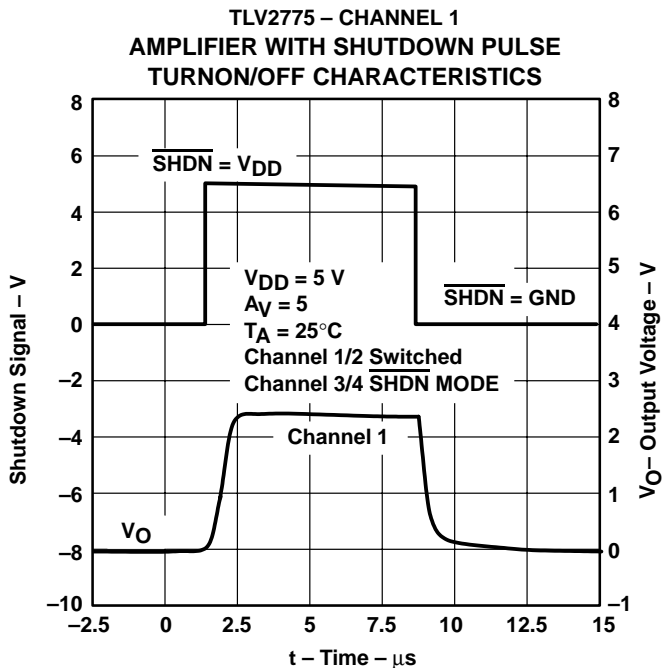


Figure 50

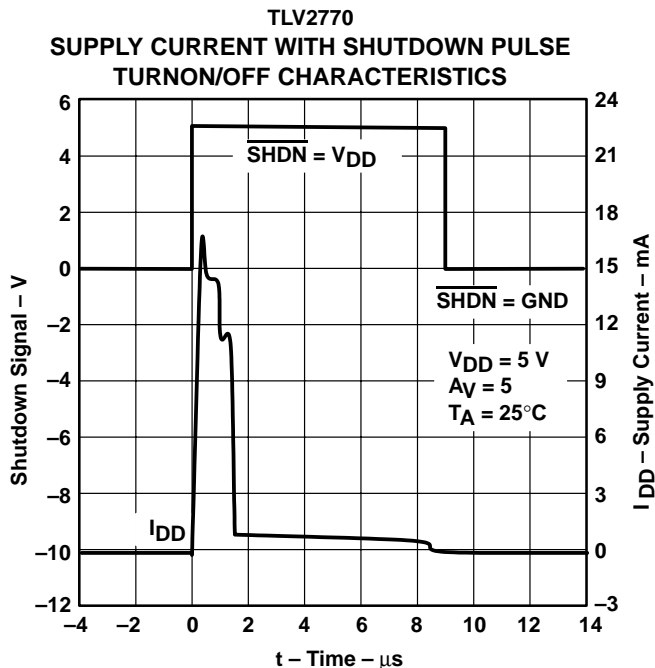


Figure 51

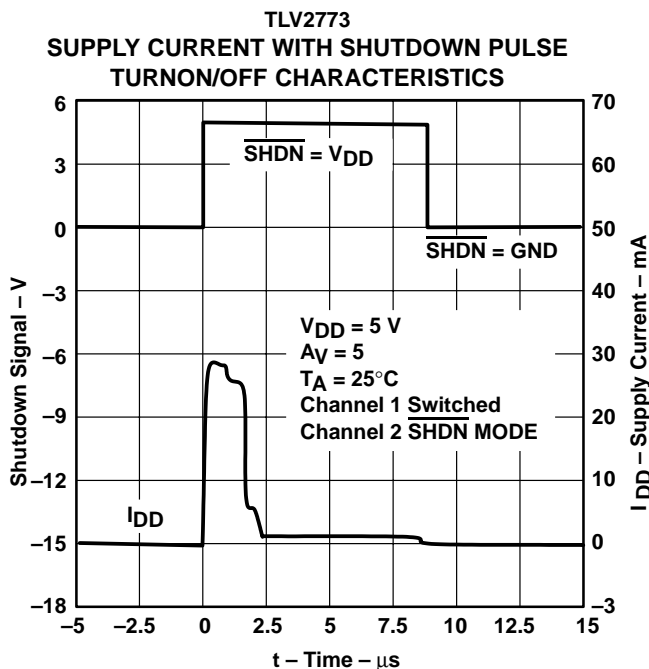


Figure 52

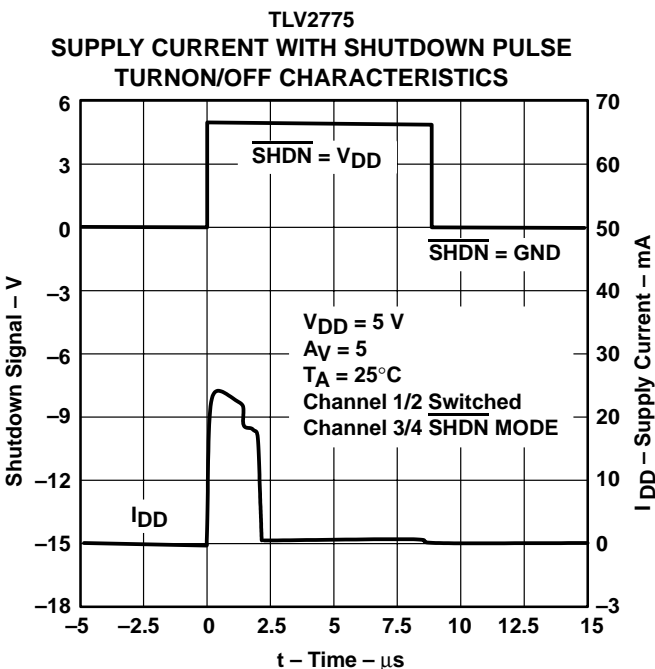


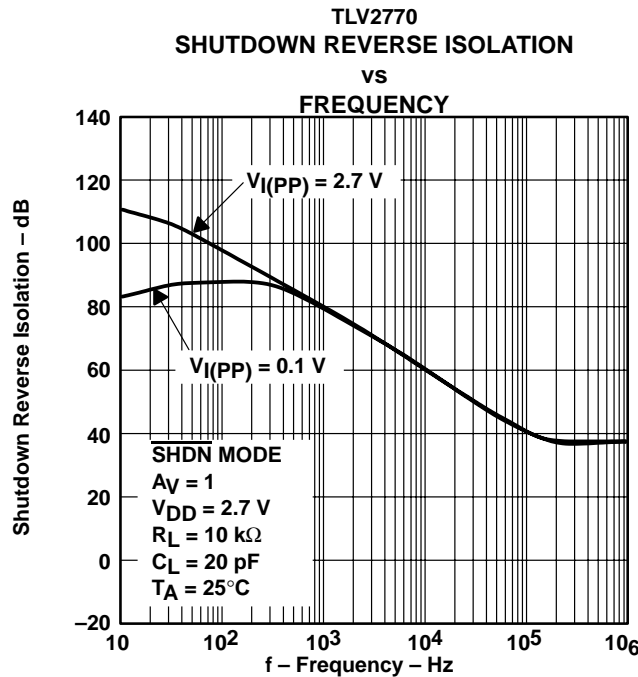
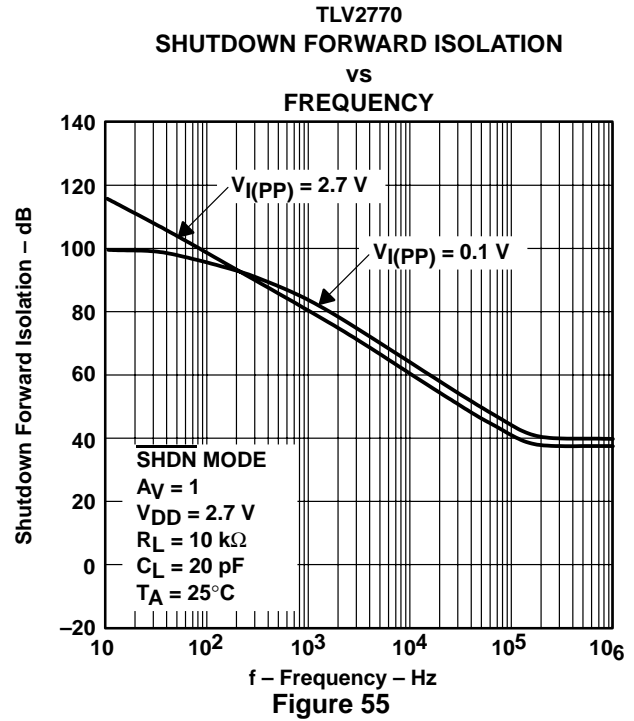
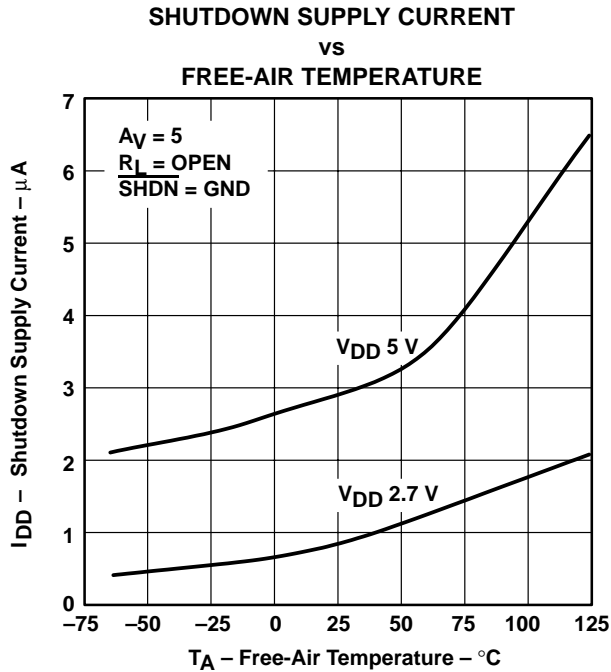
Figure 53



TLV277x, TLV277xA
**FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
 OPERATIONAL AMPLIFIERS WITH SHUTDOWN**

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TYPICAL CHARACTERISTICS



TLV277x, TLV277xA FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS WITH SHUTDOWN

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PARAMETER MEASUREMENT INFORMATION

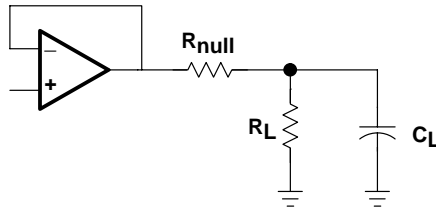


Figure 57

driving a capacitive load

When the amplifier is configured in this manner, capacitive loading directly on the output will decrease the device's phase margin leading to high frequency ringing or oscillations. Therefore, for capacitive loads of greater than 10 pF, it is recommended that a resistor be placed in series (R_{NULL}) with the output of the amplifier, as shown in Figure 58. A minimum value of 20 Ω should work well for most applications.

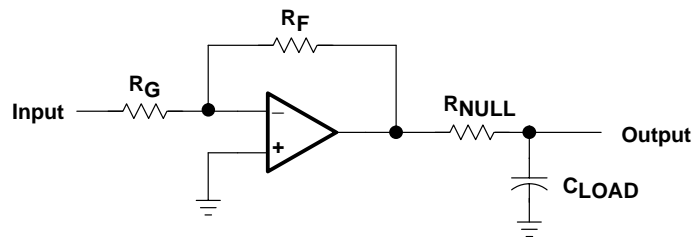


Figure 58. Driving a Capacitive Load

APPLICATION INFORMATION

offset voltage

The output offset voltage, (V_{OO}) is the sum of the input offset voltage (V_{IO}) and both input bias currents (I_{IB}) times the corresponding gains. The following schematic and formula can be used to calculate the output offset voltage:

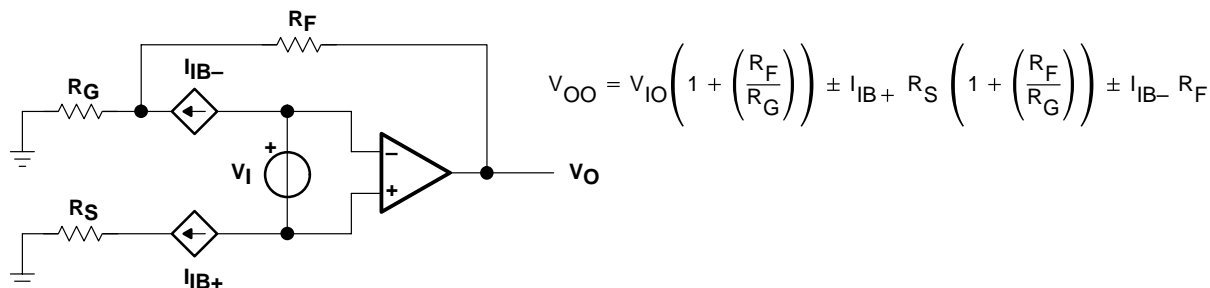


Figure 59. Output Offset Voltage Model

general configurations

When receiving low-level signals, limiting the bandwidth of the incoming signals into the system is often required. The simplest way to accomplish this is to place an RC filter at the noninverting terminal of the amplifier (see Figure 60).

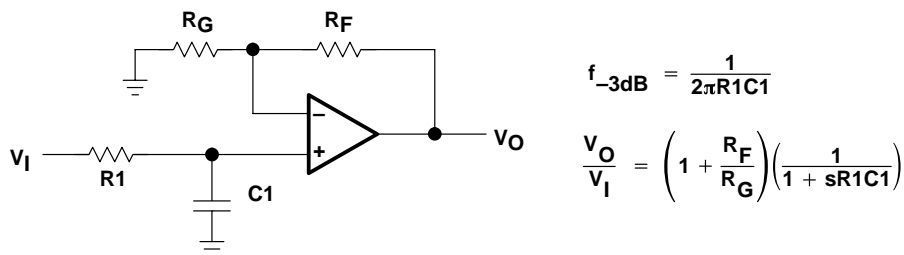


Figure 60. Single-Pole Low-Pass Filter

If even more attenuation is needed, a multiple pole filter is required. The Sallen-Key filter can be used for this task. For best results, the amplifier should have a bandwidth that is 8 to 10 times the filter frequency bandwidth. Failure to do this can result in phase shift of the amplifier.

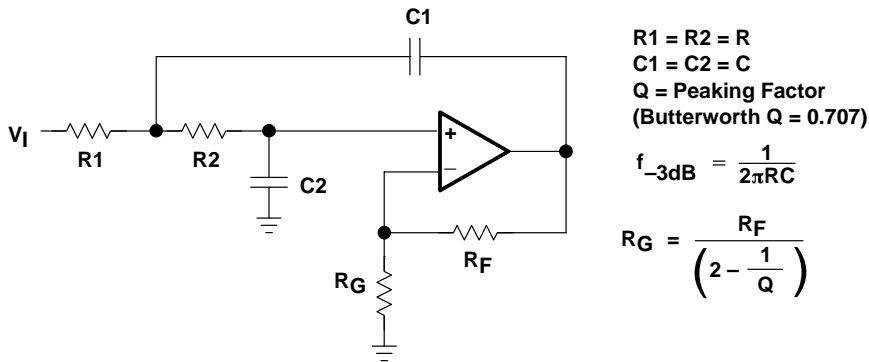


Figure 61. 2-Pole Low-Pass Sallen-Key Filter

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APPLICATION INFORMATION

using the TLV2772 as an accelerometer interface

The schematic, shown in Figure 62, shows the ACH04-08-05 interfaced to the TLV1544 10-bit analog-to-digital converter (ADC).

The ACH04-08-05 is a shock sensor designed to convert mechanical acceleration into electrical signals. The sensor contains three piezoelectric sensing elements oriented to simultaneously measure acceleration in three orthogonal, linear axes (x, y, z). The operating frequency is 0.5 Hz to 5 kHz. The output is buffered with an internal JFET and has a typical output voltage of 1.80 mV/g for the x and y axis and 1.35 mV/g for the z axis.

Amplification and frequency shaping of the shock sensor output is done by the TLV2772 rail-to-rail operational amplifier. The TLV2772 is ideal for this application as it offers high input impedance, good slew rate, and excellent dc precision. The rail-to-rail output swing and high output drive are perfect for driving the analog input of the TLV1544 ADC.

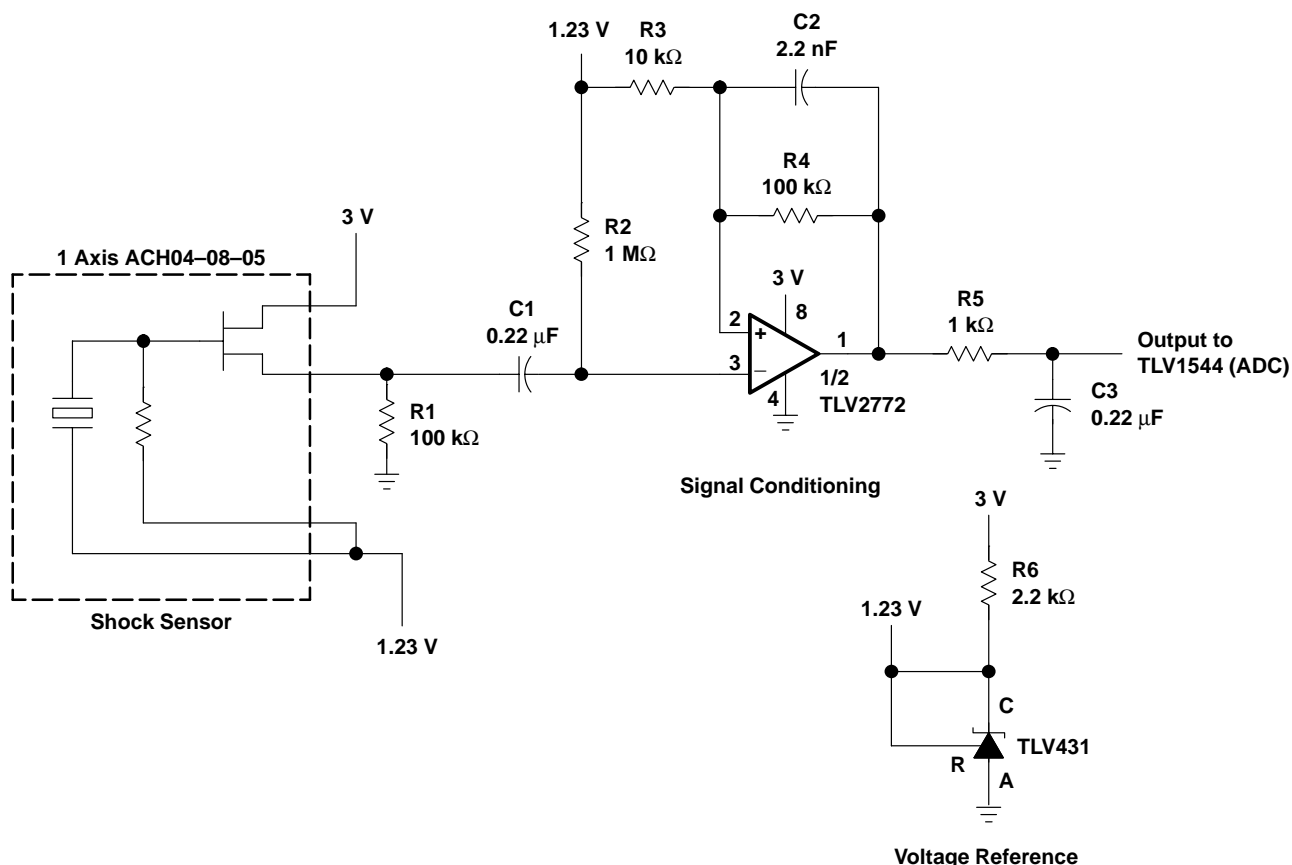


Figure 62. Accelerometer Interface Schematic

The sensor signal must be amplified and frequency-shaped to provide a signal the ADC can properly convert into the digital domain. Figure 62 shows the topology used in this application for one axis of the sensor. This system is powered from a single 3-V supply. Configuring the TLV431 with a 2.2-kΩ resistor produces a reference voltage of 1.23 V. This voltage is used to bias the operational amplifier and the internal JFETs in the shock sensor.

APPLICATION INFORMATION

gain calculation

Since the TLV2772 is capable of rail-to-rail output using a 3-V supply, $V_O = 0$ (min) to 3 V (max). With no signal from the sensor, nominal $V_O =$ reference voltage = 1.23 V. Therefore, the maximum negative swing from nominal is $0\text{ V} - 1.23\text{ V} = -1.23\text{ V}$ and the maximum positive swing is $3\text{ V} - 1.23\text{ V} = 1.77\text{ V}$. By modeling the shock sensor as a low impedance voltage source with output of 2.25 mV/g (max) in the x and y axis and 1.70 mV/g (max) in the z axis, the gain of the circuit is calculated by equation 1.

$$\text{Gain} = \frac{\text{Output Swing}}{\text{Sensor Signal} \times \text{Acceleration}} \quad (1)$$

To avoid saturation of the operational amplifier, the gain calculations are based on the maximum negative swing of -1.23 V and the maximum sensor output of 2.25 mV/g (x and y axis) and 1.70 mV/g (z axis).

$$\text{Gain (x, y)} = \frac{-1.23\text{ V}}{2.25\text{ mV/g} \times -50\text{ g}} = 10.9 \quad (2)$$

and

$$\text{Gain (z)} = \frac{-1.23\text{ V}}{1.70\text{ mV/g} \times -50\text{ g}} = 14.5 \quad (3)$$

By selecting $R_3 = 10\text{ k}\Omega$ and $R_4 = 100\text{ k}\Omega$, in the x and y channels, a gain of 11 is realized. By selecting $R_3 = 7.5\text{ k}\Omega$ and $R_4 = 100\text{ k}\Omega$, in the z channel, a gain of 14.3 is realized. The schematic shows the configuration for either the x- or y-axis.

bandwidth calculation

To calculate the component values for the frequency shaping characteristics of the signal conditioning circuit, 1 Hz and 500 Hz are selected as the minimum required 3-dB bandwidth.

To minimize the value of the input capacitor (C1) required to set the lower cutoff frequency requires a large value resistor for R2 is required. A 1-M Ω resistor is used in this example. To set the lower cutoff frequency, the required capacitor value for C1 is:

$$C1 = \frac{1}{2\pi f_{\text{LOW}} R_2} = 0.159\text{ }\mu\text{F} \quad (4)$$

Using a value of 0.22 μF , a more common value of capacitor, the lower cutoff frequency is 0.724 Hz.

To minimize the phase shift in the feedback loop caused by the input capacitance of the TLV2772, it is best to minimize the value of the feedback resistor R4. However, to reduce the required capacitance in the feedback loop a large value for R4 is required. Therefore, a compromise for the value of R4 must be made. In this circuit, a value of 100 k Ω has been selected. To set the upper cutoff frequency, the required capacitor value for C2 is:

$$C2 = \frac{1}{2\pi f_{\text{HIGH}} R_4} = 3.18\text{ }\mu\text{F} \quad (5)$$

Using a 2.2-nF capacitor, the upper cutoff frequency is 724 Hz.

R5 and C3 also cause the signal response to roll off. Therefore, it is beneficial to design this roll-off point to begin at the upper cutoff frequency. Assuming a value of 1 k Ω for R5, the value for C3 is calculated to be 0.22 μF .

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APPLICATION INFORMATION

circuit layout considerations

To achieve the levels of high performance of the TLV277x, follow proper printed-circuit board design techniques. A general set of guidelines is given in the following.

- Ground planes—It is highly recommended that a ground plane be used on the board to provide all components with a low inductive ground connection. However, in the areas of the amplifier inputs and output, the ground plane can be removed to minimize the stray capacitance.
- Proper power supply decoupling—Use a 6.8- μ F tantalum capacitor in parallel with a 0.1- μ F ceramic capacitor on each supply terminal. It may be possible to share the tantalum among several amplifiers depending on the application, but a 0.1- μ F ceramic capacitor should always be used on the supply terminal of every amplifier. In addition, the 0.1- μ F capacitor should be placed as close as possible to the supply terminal. As this distance increases, the inductance in the connecting trace makes the capacitor less effective. The designer should strive for distances of less than 0.1 inches between the device power terminals and the ceramic capacitors.
- Sockets—Sockets can be used but are not recommended. The additional lead inductance in the socket pins will often lead to stability problems. Surface-mount packages soldered directly to the printed-circuit board is the best implementation.
- Short trace runs/compact part placements—Optimum high performance is achieved when stray series inductance has been minimized. To realize this, the circuit layout should be made as compact as possible, thereby minimizing the length of all trace runs. Particular attention should be paid to the inverting input of the amplifier. Its length should be kept as short as possible. This will help to minimize stray capacitance at the input of the amplifier.
- Surface-mount passive components—Using surface-mount passive components is recommended for high performance amplifier circuits for several reasons. First, because of the extremely low lead inductance of surface-mount components, the problem with stray series inductance is greatly reduced. Second, the small size of surface-mount components naturally leads to a more compact layout thereby minimizing both stray inductance and capacitance. If leaded components are used, it is recommended that the lead lengths be kept as short as possible.

APPLICATION INFORMATION

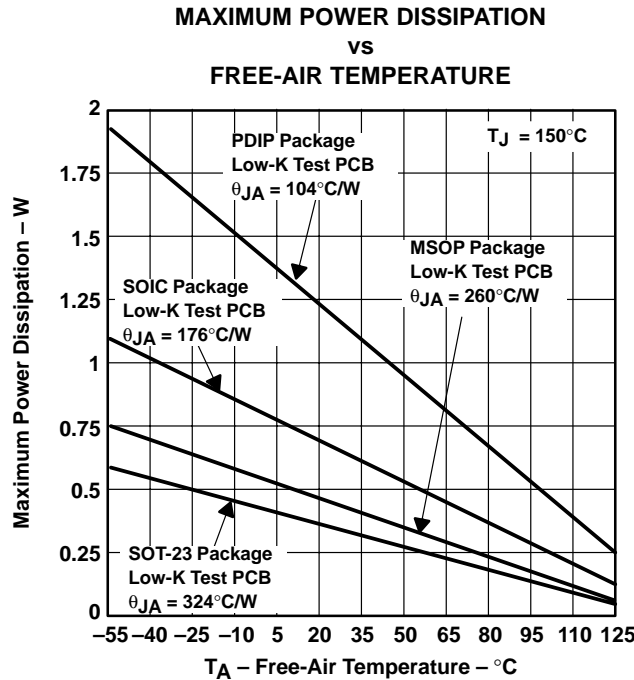
general power dissipation considerations

For a given θ_{JA} , the maximum power dissipation is shown in Figure 63 and is calculated by the following formula:

$$P_D = \left(\frac{T_{MAX} - T_A}{\theta_{JA}} \right)$$

Where:

- P_D = Maximum power dissipation of TLV277x IC (watts)
- T_{MAX} = Absolute maximum junction temperature (150°C)
- T_A = Free-ambient air temperature (°C)
- θ_{JA} = $\theta_{JC} + \theta_{CA}$
- θ_{JC} = Thermal coefficient from junction to case
- θ_{CA} = Thermal coefficient from case to ambient air (°C/W)



NOTE A: Results are with no air flow and using JEDEC Standard Low-K test PCB.

Figure 63. Maximum Power Dissipation vs Free-Air Temperature

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APPLICATION INFORMATION

shutdown function

Three members of the TLV277x family (TLV2770/3/5) have a shutdown terminal for conserving battery life in portable applications. When the shutdown terminal is tied low, the supply current is reduced to $0.8 \mu\text{A}/\text{channel}$, the amplifier is disabled, and the outputs are placed in a high impedance mode. To enable the amplifier, the shutdown terminal can either be left floating or pulled high. When the shutdown terminal is left floating, care needs to be taken to ensure that parasitic leakage current at the shutdown terminal does not inadvertently place the operational amplifier into shutdown. The shutdown terminal threshold is always referenced to $V_{DD}/2$. Therefore, when operating the device with split supply voltages (e.g. $\pm 2.5 \text{ V}$), the shutdown terminal needs to be pulled to V_{DD-} (not GND) to disable the operational amplifier.

The amplifier's output with a shutdown pulse is shown in Figures 48, 49, and 50. The amplifier is powered with a single 5-V supply and configured as a noninverting configuration with a gain of 5. The amplifier turnon and turnoff times are measured from the 50% point of the shutdown pulse to the 50% point of the output waveform. The times for the single, dual, and quad are listed in the data tables. The *bump* on the rising edge of the TLV2770 output waveform is due to the start-up circuit on the bias generator. For the dual and quad (TLV2773/5), this *bump* is attributed to the bias generator's start-up circuit as well as the crosstalk between the other channel(s), which are in shutdown.

Figures 55 and 56 show the amplifier's forward and reverse isolation in shutdown. The operational amplifier is powered by $\pm 1.35\text{-V}$ supplies and configured as a voltage follower ($A_V = 1$). The isolation performance is plotted across frequency for both 0.1 V_{PP} and 2.7 V_{PP} input signals. During normal operation, the amplifier would not be able to handle a 2.7-V_{PP} input signal with a supply voltage of $\pm 1.35 \text{ V}$ since it exceeds the common-mode input voltage range (V_{ICR}). However, this curve illustrates that the amplifier remains in shutdown even under a worst case scenario.



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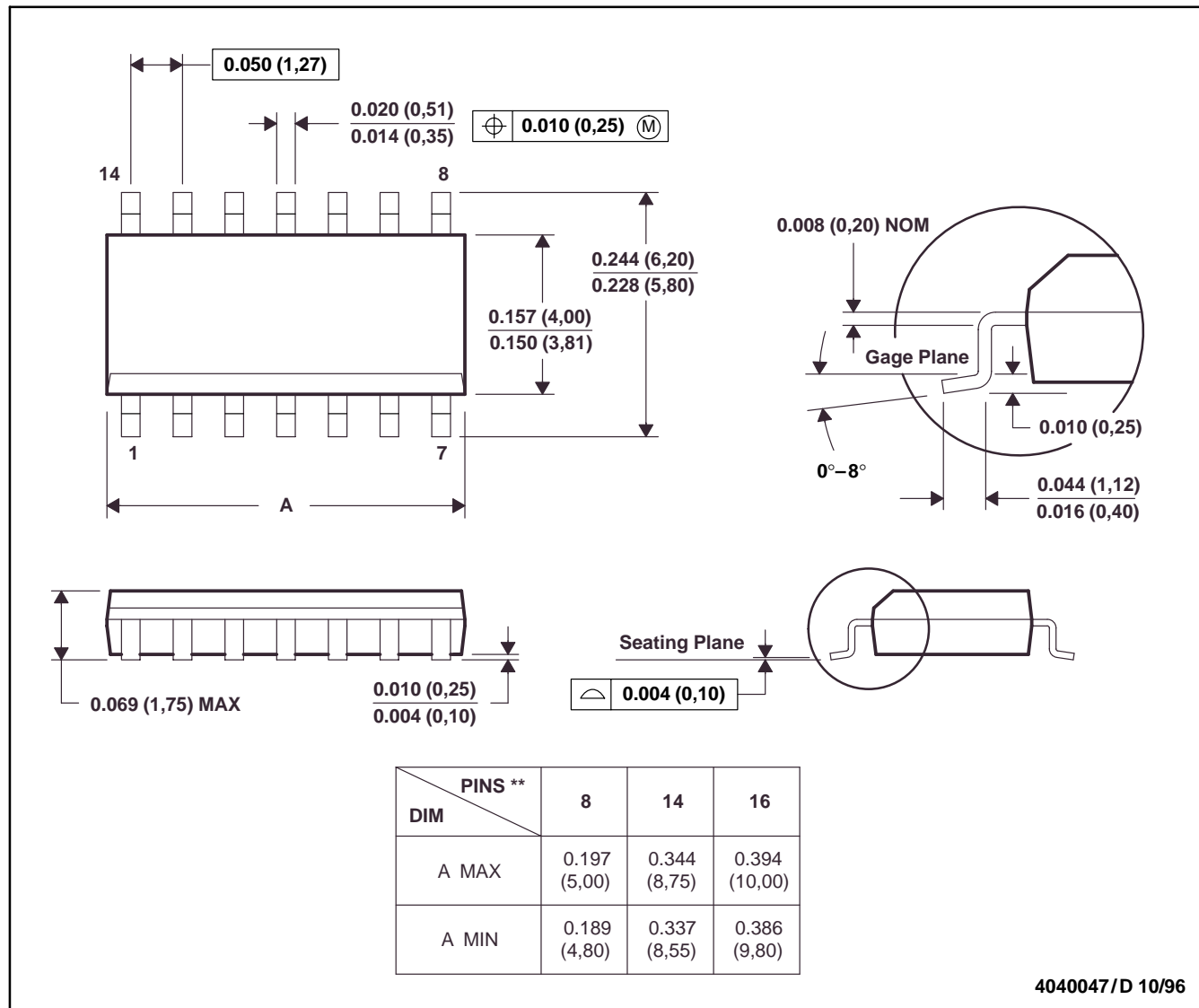
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MECHANICAL INFORMATION

D (R-PDSO-G)**

PLASTIC SMALL-OUTLINE PACKAGE

14 PIN SHOWN



- NOTES: A. All linear dimensions are in inches (millimeters).
 B. This drawing is subject to change without notice.
 C. Body dimensions do not include mold flash or protrusion, not to exceed 0.006 (0,15).
 D. Falls within JEDEC MS-012

4040047/D 10/96

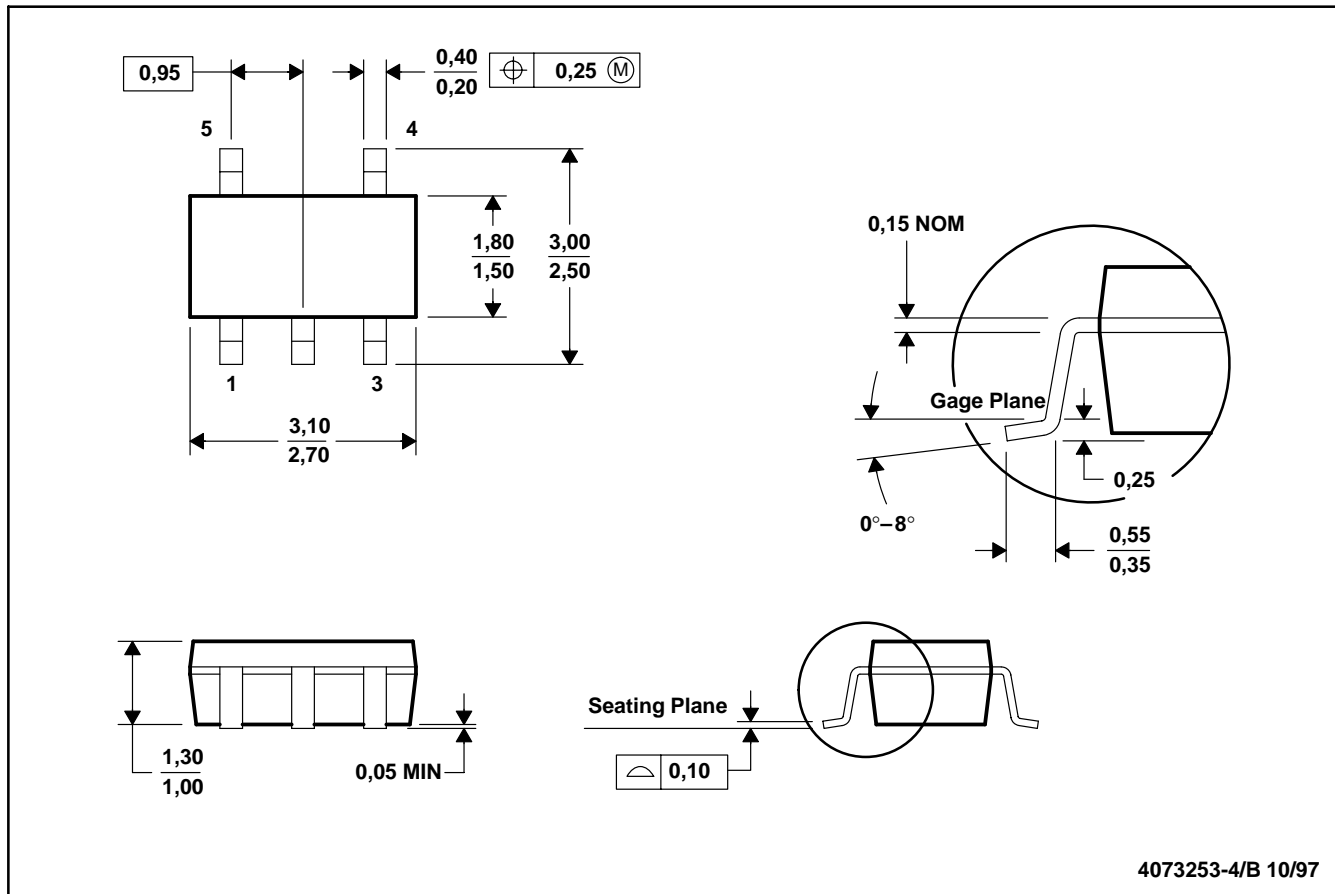
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MECHANICAL INFORMATION

DBV (R-PDSO-G5)

PLASTIC SMALL-OUTLINE PACKAGE



- NOTES: A. All linear dimensions are in millimeters.
 B. This drawing is subject to change without notice.
 C. Body dimensions include mold flash or protrusion.

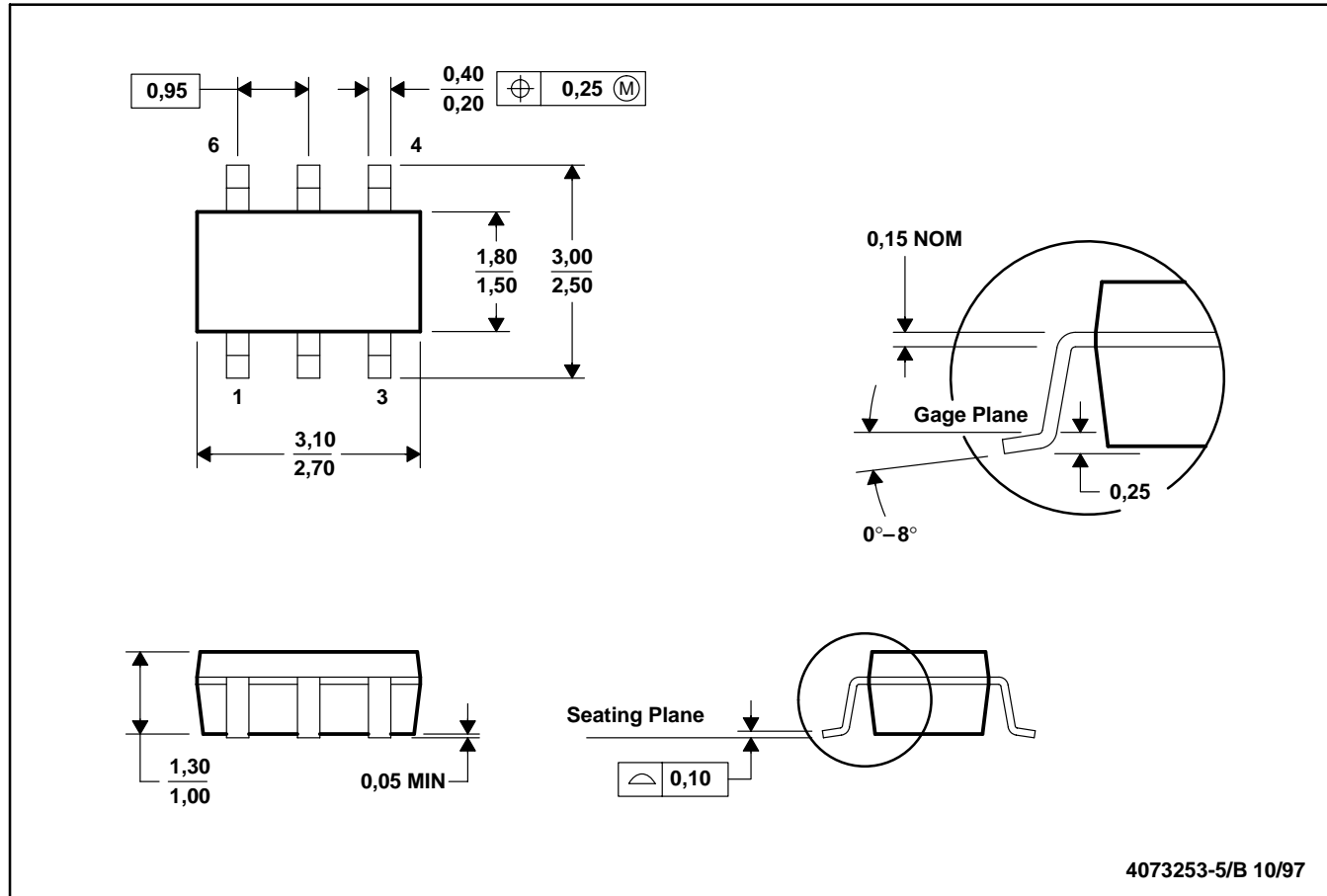
TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

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MECHANICAL INFORMATION

DBV (R-PDSO-G6)

PLASTIC SMALL-OUTLINE PACKAGE



- NOTES: A. All linear dimensions are in millimeters.
 B. This drawing is subject to change without notice.
 C. Body dimensions include mold flash or protrusion.

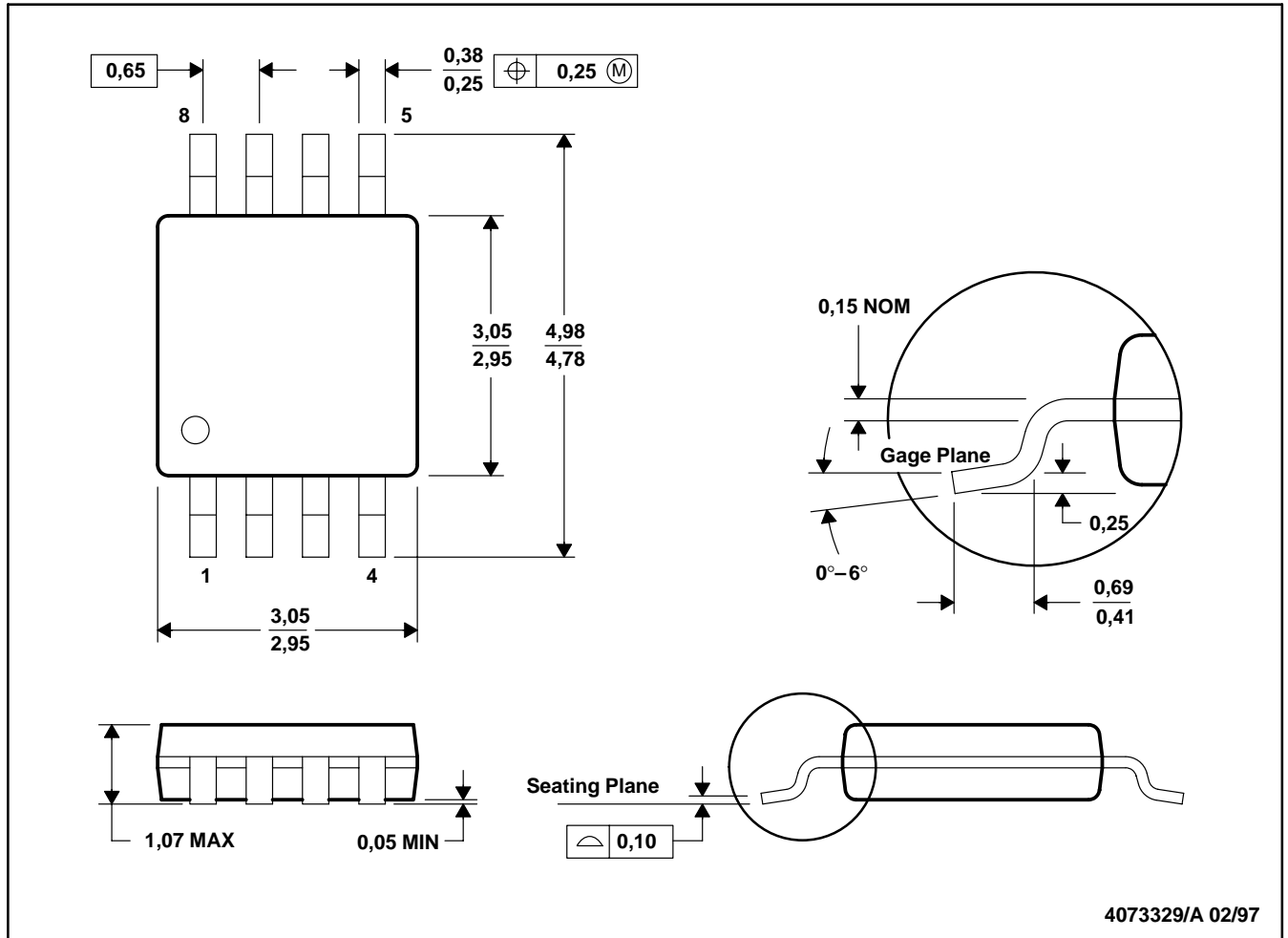
TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

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MECHANICAL INFORMATION

DGK (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.

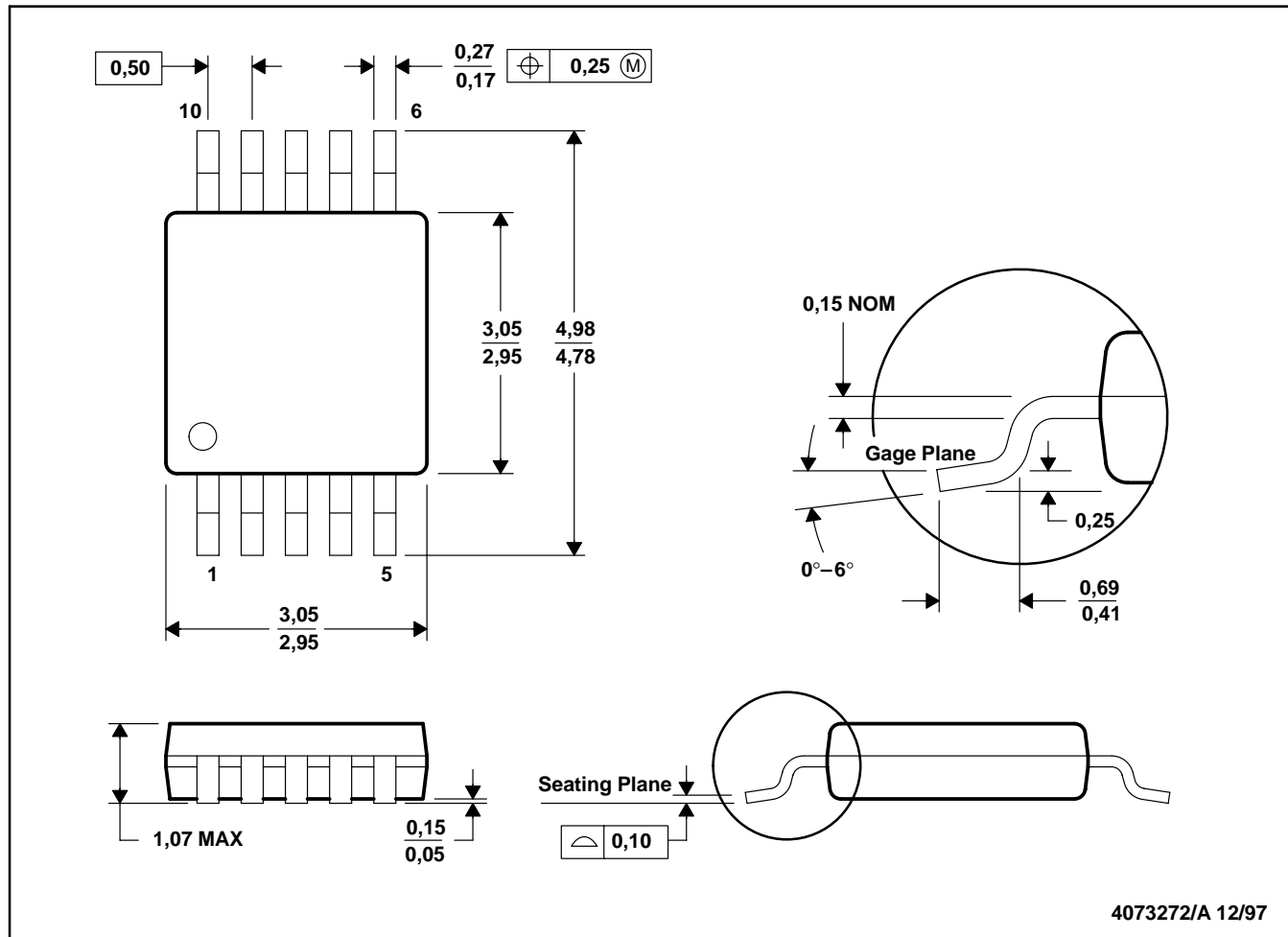
TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

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MECHANICAL INFORMATION

DGS (S-PDSO-G10)

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.

TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
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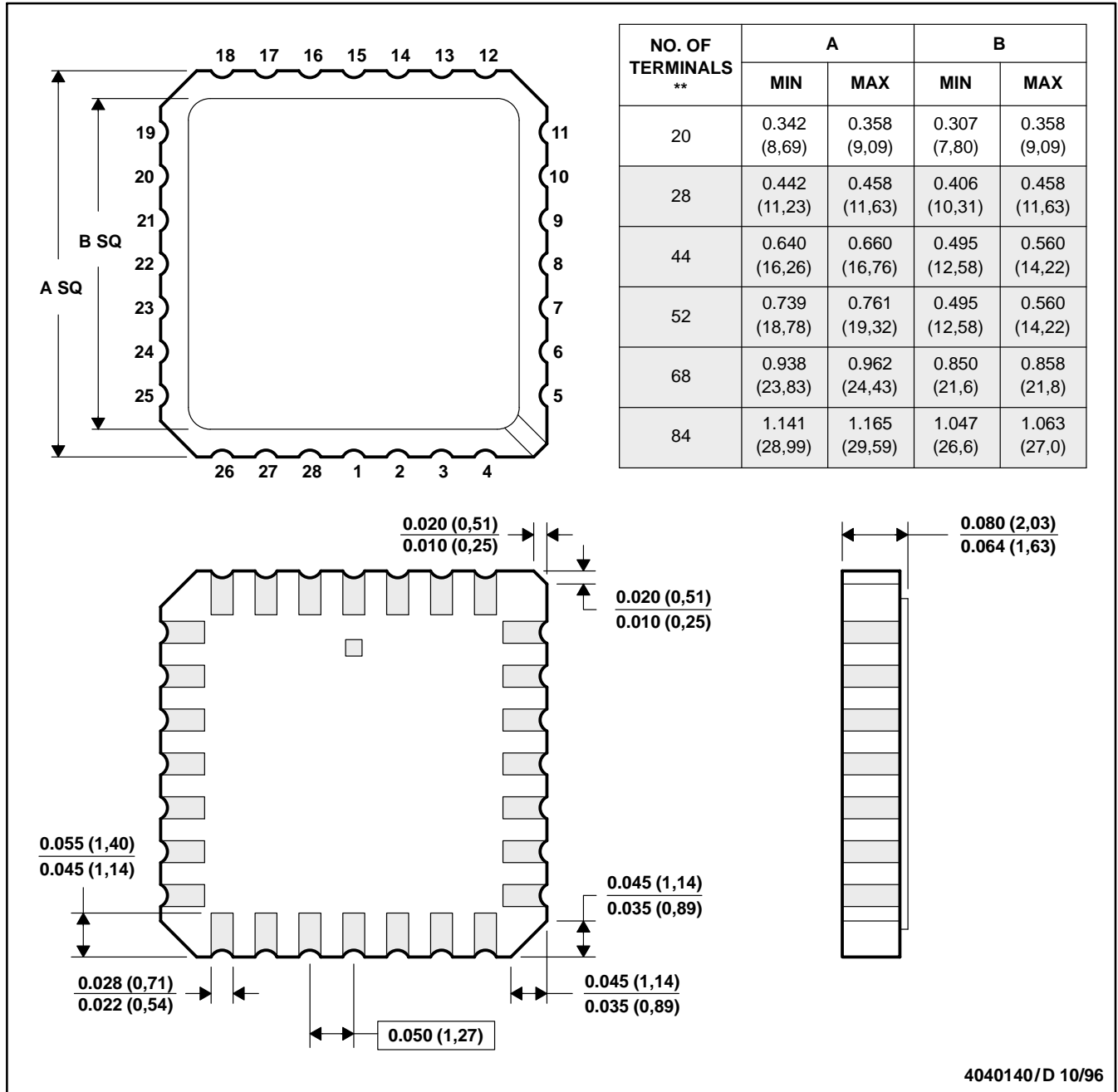
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MECHANICAL INFORMATION

FK (S-CQCC-N)**

LEADLESS CERAMIC CHIP CARRIER

28 TERMINAL SHOWN



- 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 metal lid.
 D. The terminals are gold plated.
 E. Falls within JEDEC MS-004

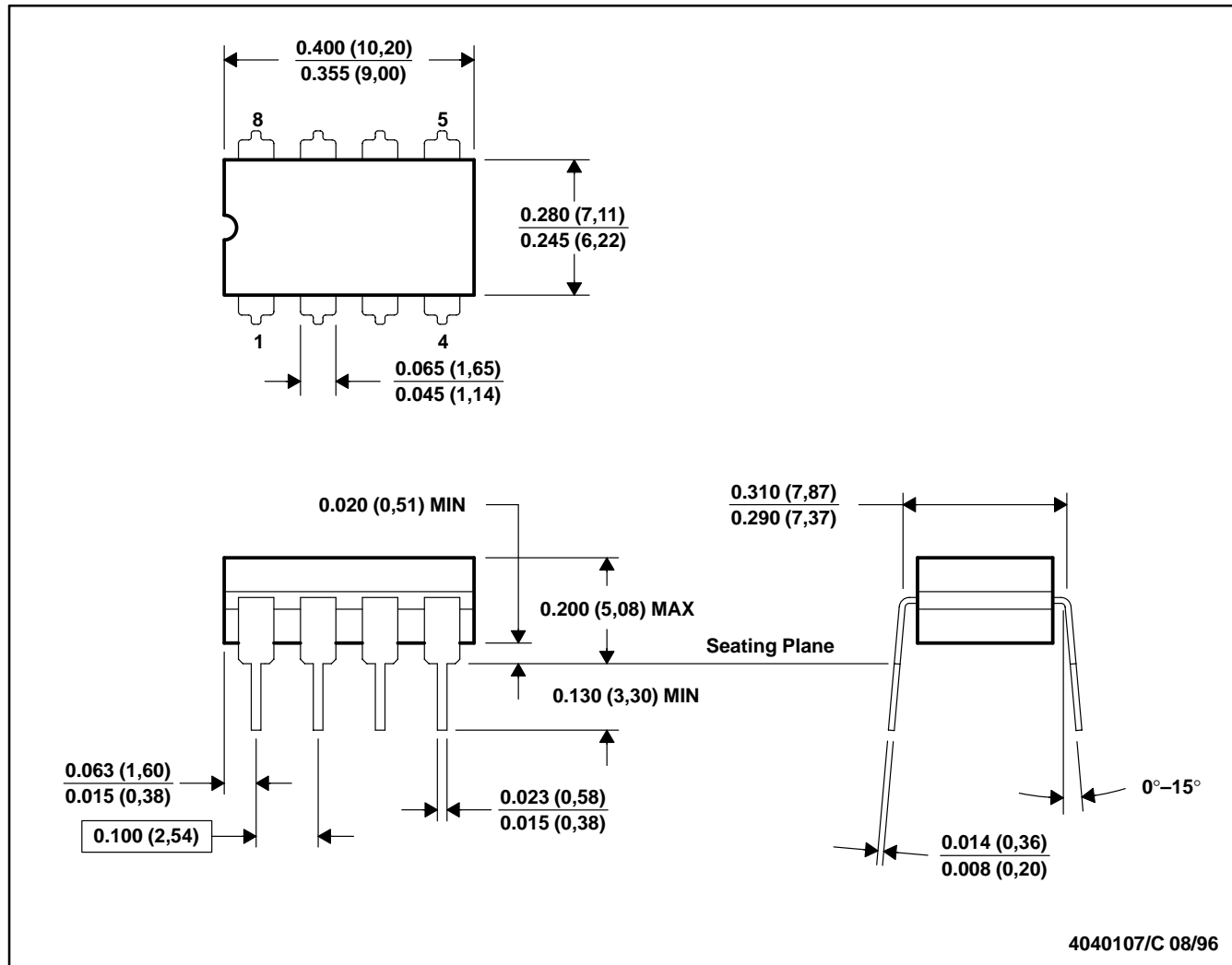
TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

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MECHANICAL INFORMATION

JG (R-GDIP-T8)

CERAMIC DUAL-IN-LINE PACKAGE



- 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 on press ceramic glass frit seal.
 E. Falls within MIL-STD-1835 GDIP1-T8

TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

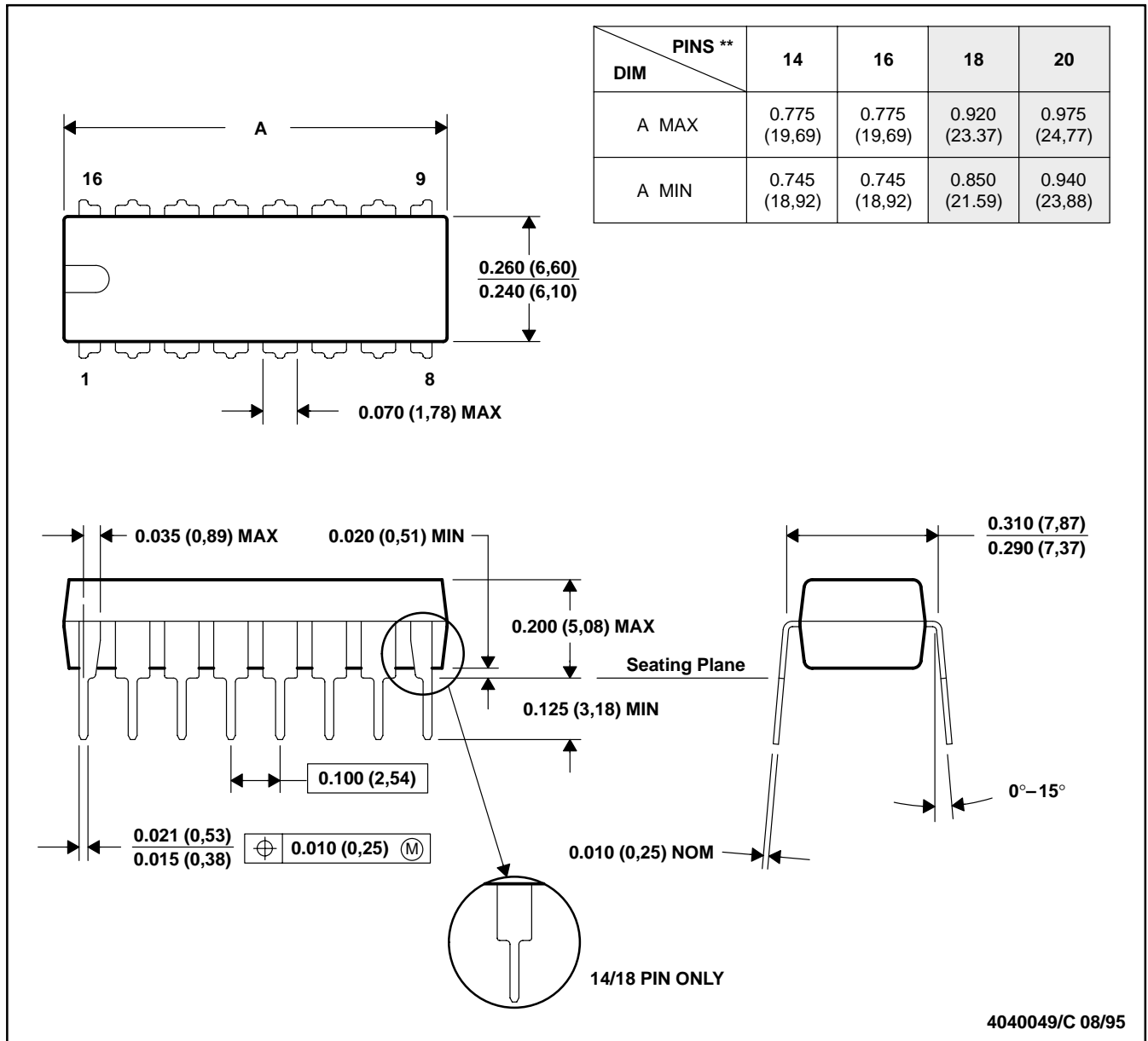
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MECHANICAL INFORMATION

N (R-PDIP-T)**

PLASTIC DUAL-IN-LINE PACKAGE

16 PIN SHOWN



- NOTES: A. All linear dimensions are in inches (millimeters).
 B. This drawing is subject to change without notice.
 C. Falls within JEDEC MS-001 (20 pin package is shorter than MS-001.)

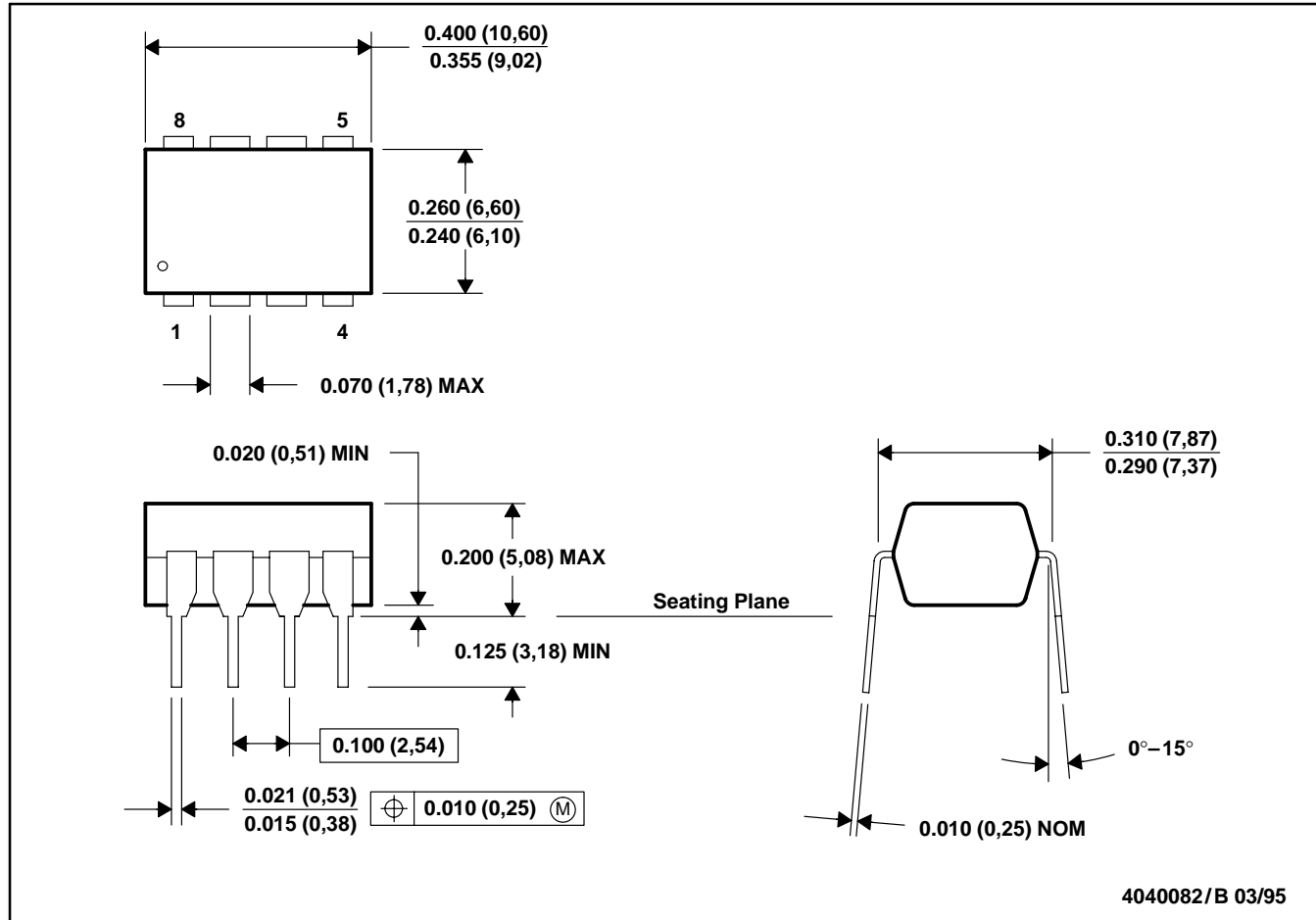
TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

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MECHANICAL INFORMATION

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

TLV277x, TLV277xA
FAMILY OF 2.7-V HIGH-SLEW-RATE RAIL-TO-RAIL OUTPUT
OPERATIONAL AMPLIFIERS WITH SHUTDOWN

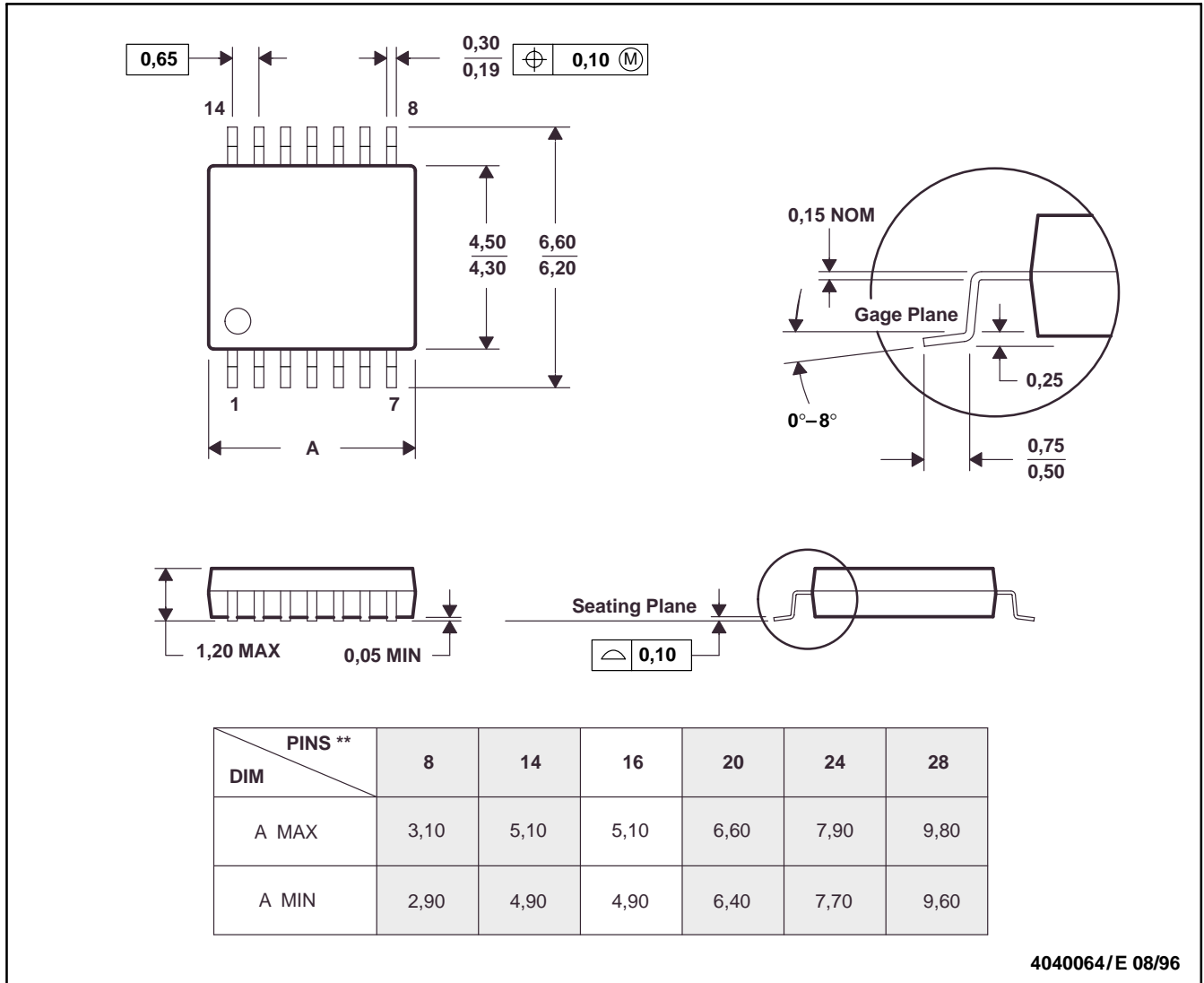
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MECHANICAL INFORMATION

PW (R-PDSO-G)**

PLASTIC SMALL-OUTLINE PACKAGE

14 PIN SHOWN



- 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.
 D. Falls within JEDEC MO-153

JG (R-GDIP-T8)

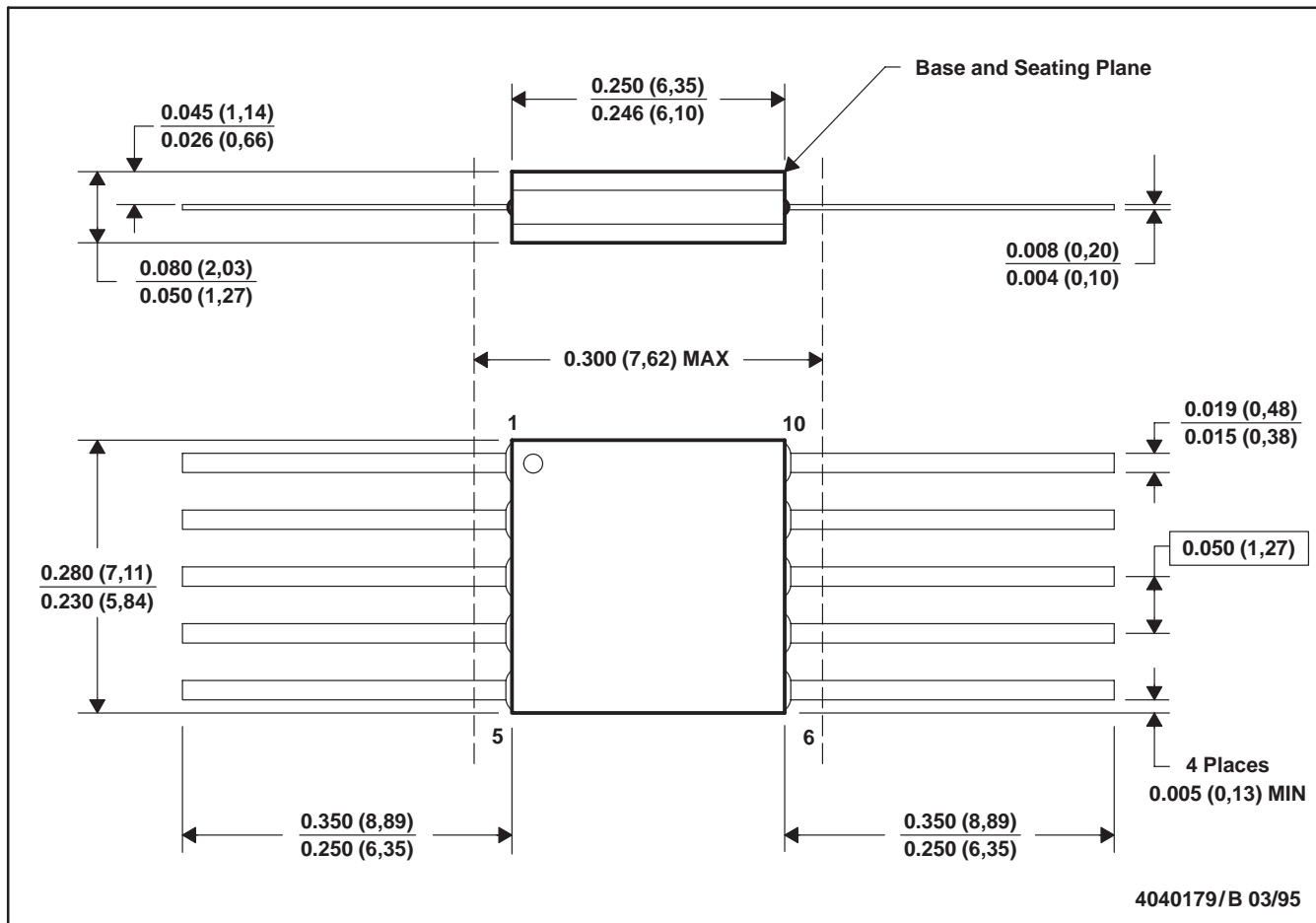
CERAMIC DUAL-IN-LINE



- 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

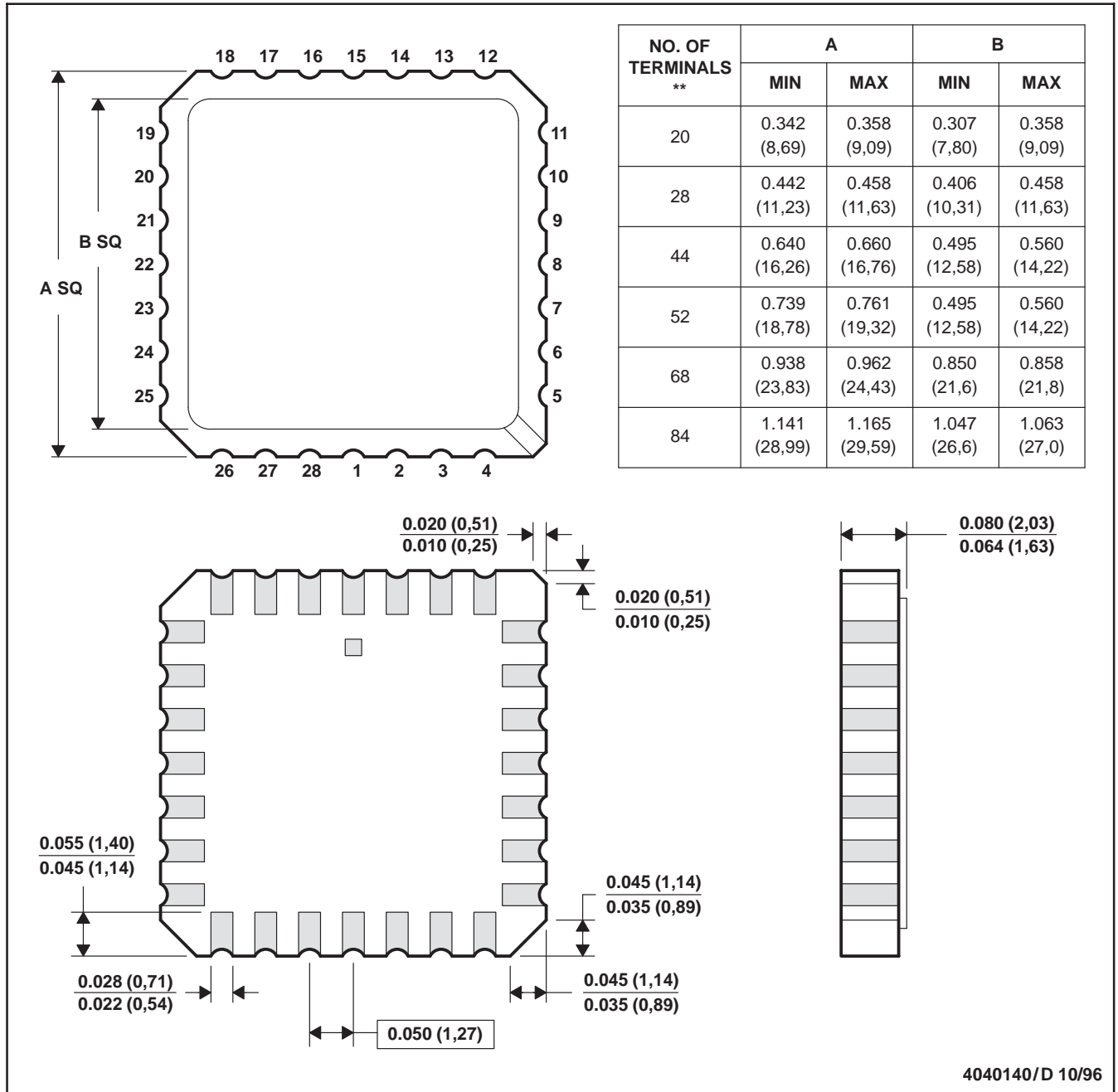


- NOTES: A. All linear dimensions are in inches (millimeters).
 B. This drawing is subject to change without notice.
 C. This package can be hermetically sealed with a ceramic lid using glass frit.
 D. Index point is provided on cap for terminal identification only.
 E. Falls within MIL STD 1835 GDFP1-F10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

FK (S-CQCC-N**)

LEADLESS CERAMIC CHIP CARRIER

28 TERMINAL SHOWN



- 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 metal lid.
 - D. The terminals are gold plated.
 - E. Falls within JEDEC MS-004

P (R-PDIP-T8)

PLASTIC DUAL-IN-LINE



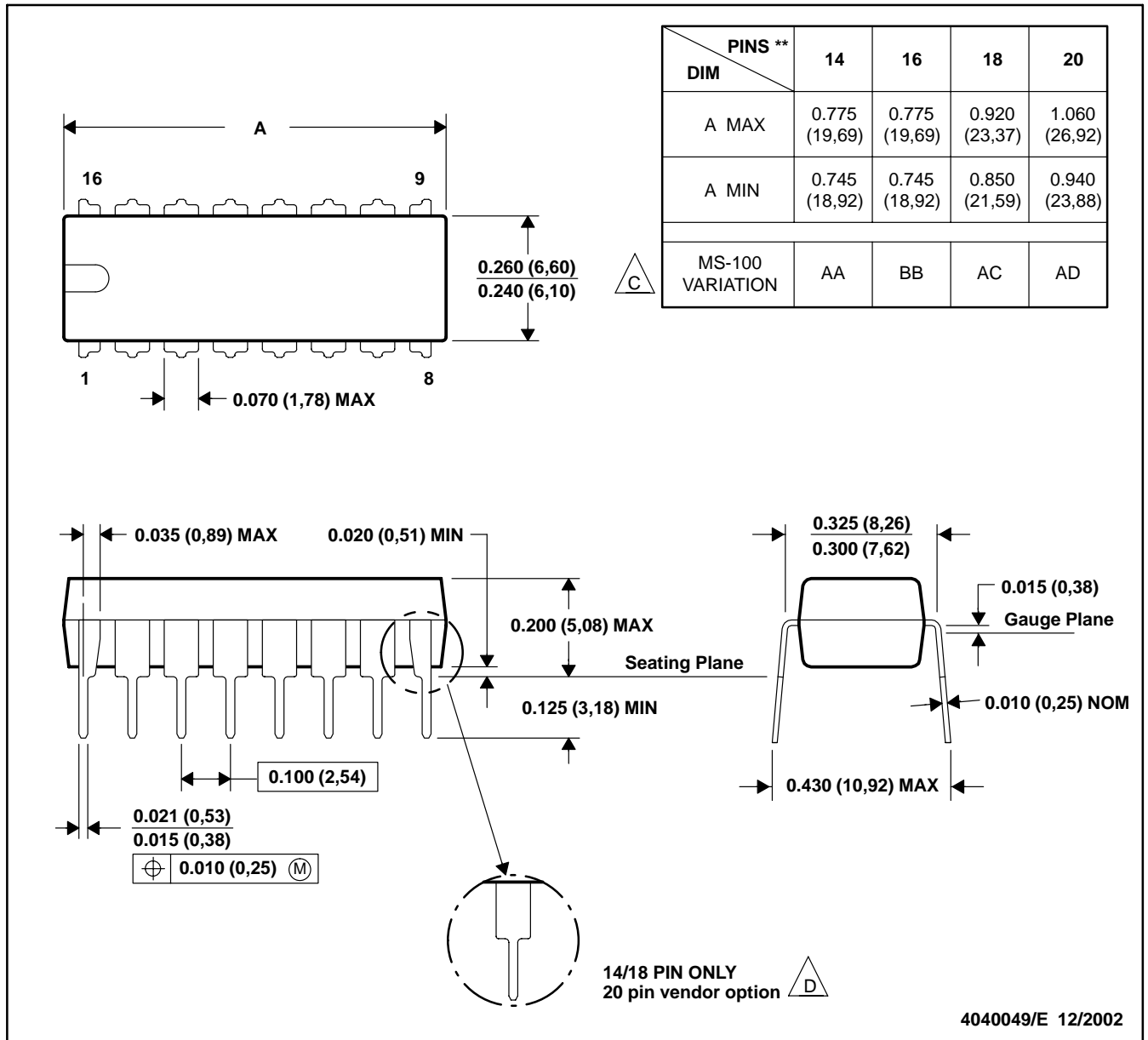
- NOTES: A. All linear dimensions are in inches (millimeters).
 B. This drawing is subject to change without notice.
 C. Falls within JEDEC MS-001

For the latest package information, go to http://www.ti.com/sc/docs/package/pkg_info.htm

N (R-PDIP-T**)

PLASTIC DUAL-IN-LINE PACKAGE

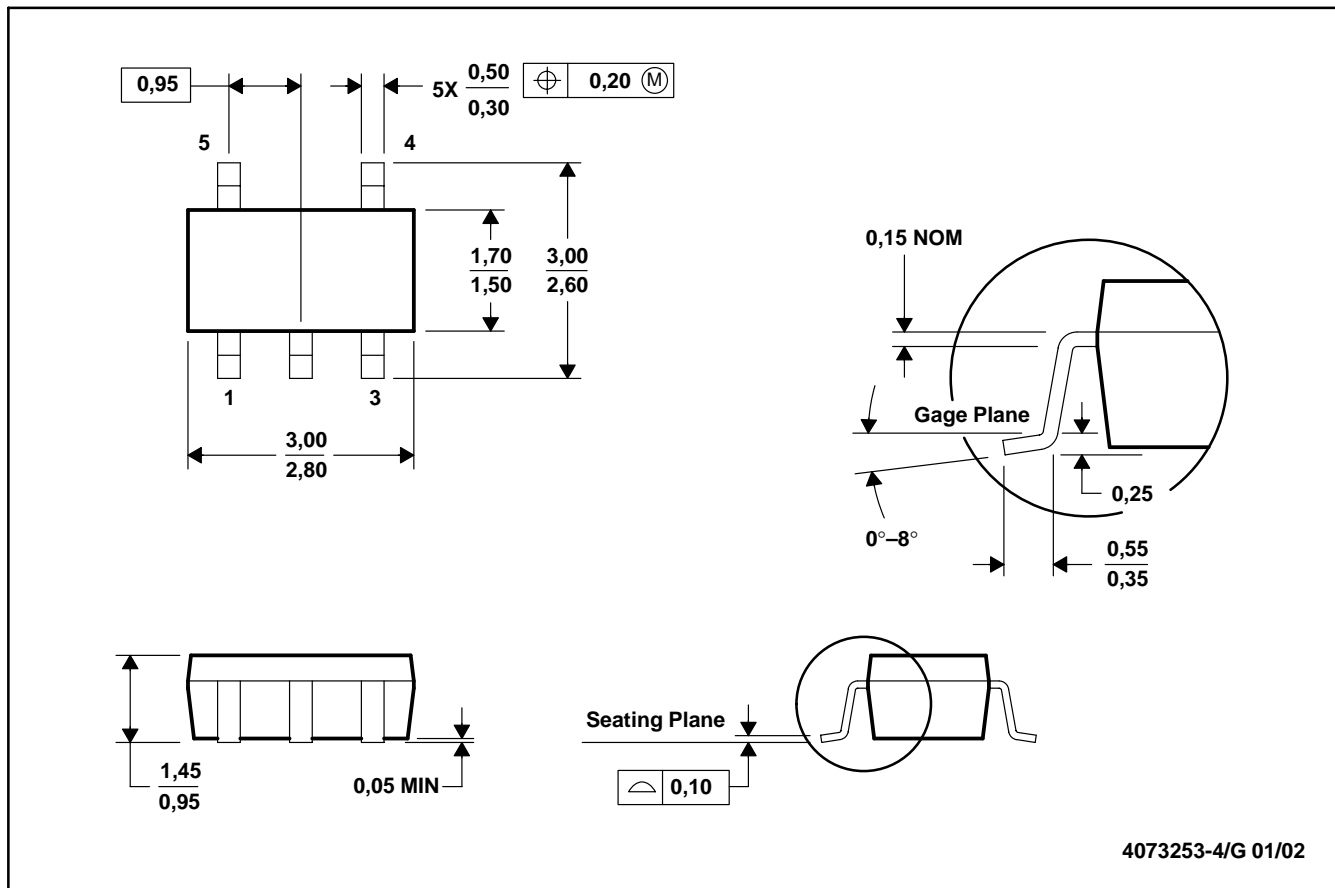
16 PINS SHOWN



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

DBV (R-PDSO-G5)

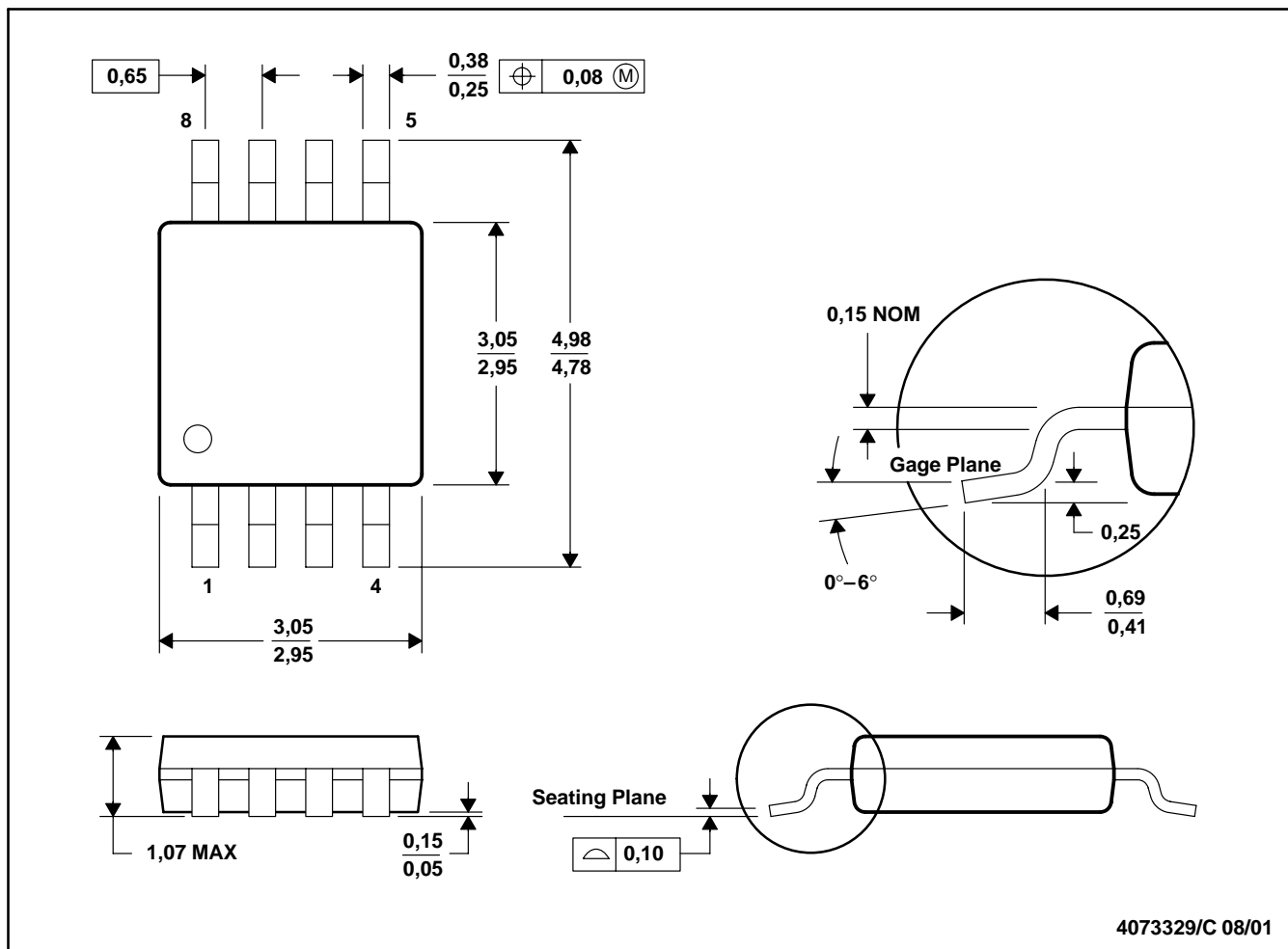
PLASTIC SMALL-OUTLINE



- 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.
 D. Falls within JEDEC MO-178

DGK (R-PDSO-G8)

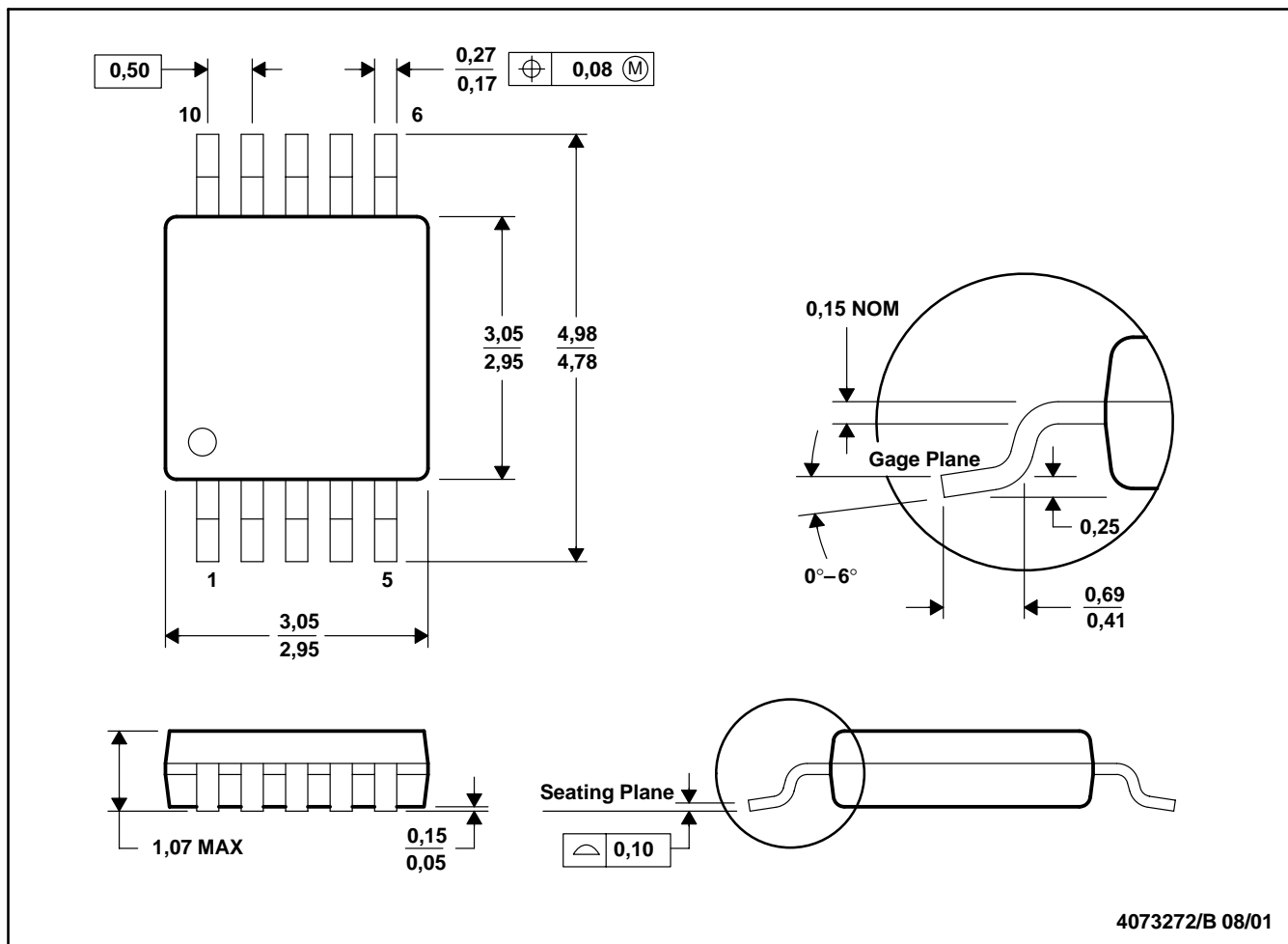
PLASTIC SMALL-OUTLINE PACKAGE



- 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.
 D. Falls within JEDEC MO-187

DGS (S-PDSO-G10)

PLASTIC SMALL-OUTLINE PACKAGE

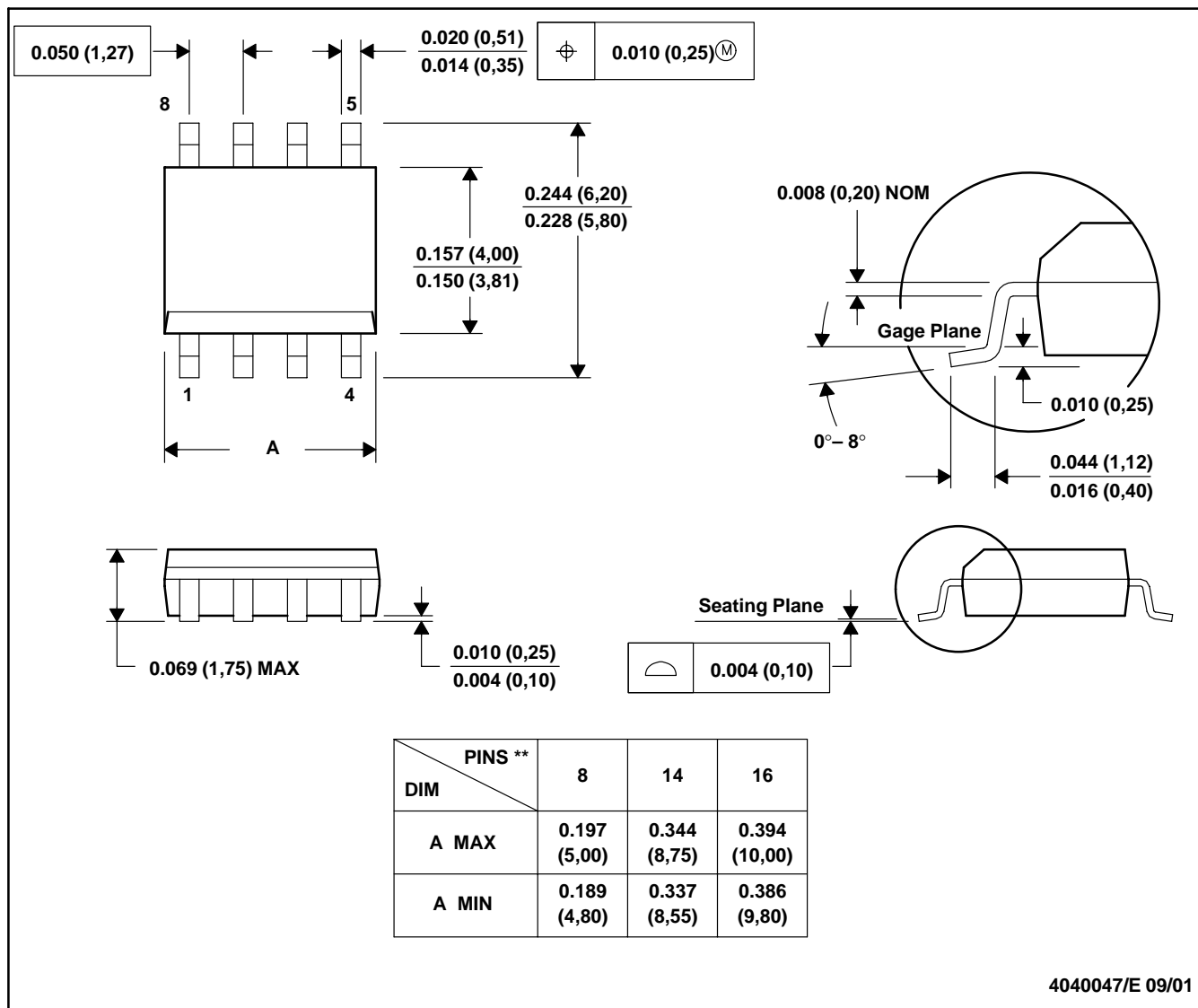


- NOTES: A. All linear dimensions are in millimeters.
 B. This drawing is subject to change without notice.
 C. Body dimensions do not include mold flash or protrusion.
 D. Falls within JEDEC MO-187

D (R-PDSO-G**)

PLASTIC SMALL-OUTLINE PACKAGE

8 PINS SHOWN



4040047/E 09/01

- NOTES: A. All linear dimensions are in inches (millimeters).
 B. This drawing is subject to change without notice.
 C. Body dimensions do not include mold flash or protrusion, not to exceed 0.006 (0,15).
 D. Falls within JEDEC MS-012

PW (R-PDSO-G**)

PLASTIC SMALL-OUTLINE PACKAGE

14 PINS SHOWN



- 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.
 D. Falls within JEDEC MO-153

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