

TLC4501, TLC4501A, TLC4502, TLC4502A  
**FAMILY OF SELF-CALIBRATING (Self-Cal™)**  
**PRECISION CMOS RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS**

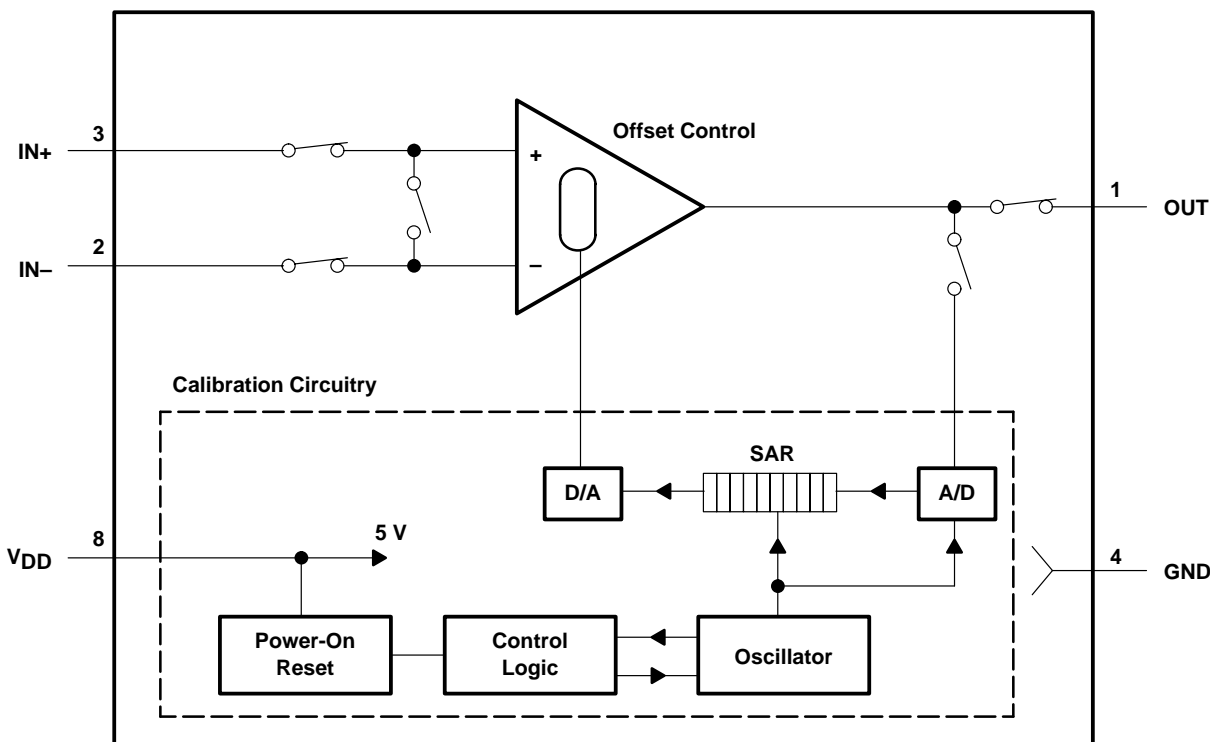
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- Self-Calibrates Input Offset Voltage to 40  $\mu\text{V}$  Max
- Low Input Offset Voltage Drift . . . 1  $\mu\text{V}/^\circ\text{C}$
- Input Bias Current . . . 1 pA
- Open Loop Gain . . . 120 dB
- Rail-To-Rail Output Voltage Swing
- Stable Driving 1000 pF Capacitive Loads
- Gain Bandwidth Product . . . 4.7 MHz
- Slew Rate . . . 2.5 V/ $\mu\text{s}$
- High Output Drive Capability . . .  $\pm 50$  mA
- Calibration Time . . . 300 ms
- Characterized From  $-55^\circ\text{C}$  to  $125^\circ\text{C}$
- Available in Q-Temp Automotive HighRel Automotive Applications Configuration Control / Print Support Qualification to Automotive Standards

**description**

The TLC4501 and TLC4502 are the highest precision CMOS single supply rail-to-rail operational amplifiers available today. The input offset voltage is 10  $\mu\text{V}$  typical and 40  $\mu\text{V}$  maximum. This exceptional precision, combined with a 4.7-MHz bandwidth, 2.5-V/ $\mu\text{s}$  slew rate, and 50-mA output drive, is ideal for multiple applications including: data acquisition systems, measurement equipment, industrial control applications, and portable digital scales.

These amplifiers feature *self-calibrating* circuitry which digitally trims the input offset voltage to less than 40  $\mu\text{V}$  within the first 300 ms of operation. The offset is then digitally stored in an integrated successive approximation register (SAR). Immediately after the data is stored, the calibration circuitry effectively drops out of the signal path, shuts down, and the device functions as a standard operational amplifier.



**Figure 1. Channel One of the TLC4502**



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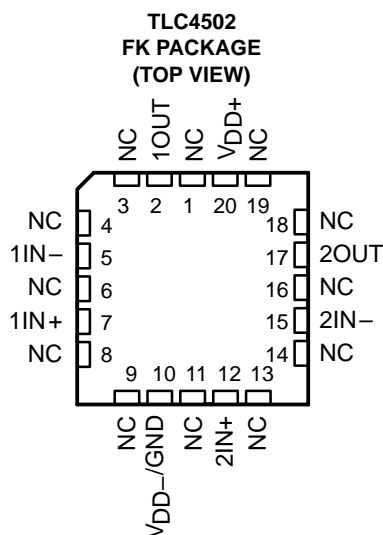
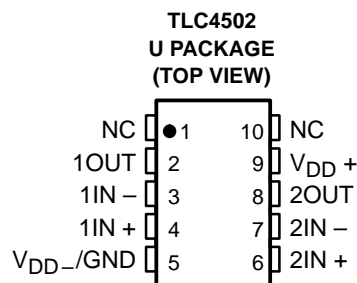
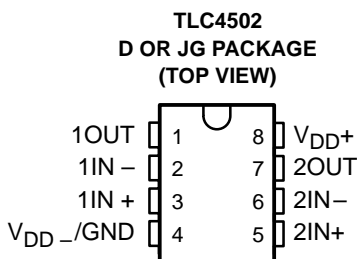
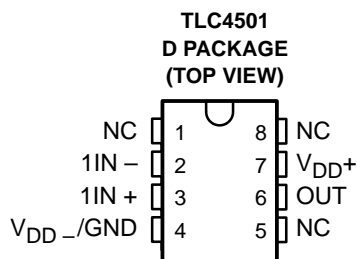
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 On products compliant to MIL-PRF-38535, all parameters are tested unless otherwise noted. On all other products, production processing does not necessarily include testing of all parameters.

# TLC4501, TLC4501A, TLC4502, TLC4502A FAMILY OF SELF-CALIBRATING (Self-Cal™) PRECISION CMOS RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS

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## description (continued)

Using this technology eliminates the need for noisy and expensive chopper techniques, laser trimming, and power hungry, split supply bipolar operational amplifiers.



NC – No internal connection

### AVAILABLE OPTIONS

T <sub>A</sub>	V <sub>IO</sub> max AT 25°C	PACKAGED DEVICES			
		SMALL OUTLINE† (D)	CHIP CARRIER (FK)	CERAMIC DIP (JG)	CERAMIC FLAT PACK (U)
0°C to 70°C	40 μV	TLC4501ACD	—	—	—
	50 μV	TLC4502ACD	—	—	—
	80 μV	TLC4501CD	—	—	—
	100 μV	TLC4502CD	—	—	—
–40°C to 125°C	40 μV	TLC4501AID	—	—	—
	50 μV	TLC4502AID	—	—	—
	80 μV	TLC4501ID	—	—	—
	100 μV	TLC4502ID	—	—	—
–40°C to 125°C	50 μV	TLC4502AQD	—	—	—
	100 μV	TLC4502QD	—	—	—
–55°C to 125°C	50 μV	TLC4502AMD	TLC4502AMFKB	TLC4502AMJGB	TLC4502AMUB
	100 μV	TLC4502MD	TLC4502MFKB	TLC4502MJGB	TLC4502MUB

† The D package is also available taped and reeled.



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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)	$\pm 7$ V
Input voltage range, $V_I$ (any input, see Note 1)	–0.3 V to 7 V
Input current, $I_I$ (each input)	$\pm 5$ mA
Output current, $I_O$ (each output)	$\pm 100$ mA
Total current into $V_{DD+}$	$\pm 100$ mA
Total current out of $V_{DD-}/GND$	$\pm 100$ mA
Electrostatic discharge (ESD)	> 2 kV
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, $T_A$ : TLC4502C	0°C to 70°C
TLC4502I	–40°C to 125°C
TLC4502Q	–40°C to 125°C
TLC4502M	–55°C to 125°C
Storage temperature range, $T_{stg}$	–65°C to 150°C
Case temperature for 60 seconds, $T_C$ : FK package	260°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: 1. All voltage values, except differential voltages, are with respect to  $V_{DD-}/GND$ .  
2. Differential voltages are at  $IN+$  with respect to  $IN-$ . Excessive current flows when an input is brought below  $V_{DD-} - 0.3$  V.  
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.

**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
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
U	675 mW	5.4 mW/°C	432 mW	350 mW	135 mW

**recommended operating conditions**

	TLC4502C		TLC4502I		TLC4502Q		TLC4502M		UNIT
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	
Supply voltage, $V_{DD}$	4	6	4	6	4	6	4	6	V
Input voltage range, $V_I$	$V_{DD-}$	$V_{DD+} - 2.3$	$V_{DD-}$	$V_{DD+} - 2.3$	$V_{DD-}$	$V_{DD+} - 2.3$	$V_{DD-}$	$V_{DD+} - 2.3$	V
Common-mode input voltage, $V_{IC}$	$V_{DD-}$	$V_{DD+} - 2.3$	$V_{DD-}$	$V_{DD+} - 2.3$	$V_{DD-}$	$V_{DD+} - 2.3$	$V_{DD-}$	$V_{DD+} - 2.3$	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,  $V_{DD} = 5\text{ V}$ ,  $GND = 0$  (unless otherwise noted)

PARAMETER	TEST CONDITIONS	$T_A$ †	TLC450xC			UNIT	
			MIN	TYP	MAX		
$V_{IO}$ Input offset voltage	$V_{DD} = \pm 2.5\text{ V}$ , $V_O = 0$ , $V_{IC} = 0$ , $R_S = 50\ \Omega$	Full range	TLC4501	-80	10	80	$\mu\text{V}$
			TLC4501A	-40	10	40	
			TLC4502	-100	10	100	
			TLC4502A	-50	10	50	
$\alpha_{VIO}$ Temperature coefficient of input offset voltage		Full range		1		$\mu\text{V}/^\circ\text{C}$	
$I_{IO}$ Input offset current	$V_{DD} = \pm 2.5\text{ V}$ , $V_O = 0$ , $V_{IC} = 0$ , $R_S = 50\ \Omega$	25°C		1	60	$\text{pA}$	
		Full range			500		
$I_{IB}$ Input bias current		25°C		1	60	$\text{pA}$	
		Full range			500		
$V_{OH}$ High-level output voltage	$I_{OH} = -500\ \mu\text{A}$	25°C		4.99		V	
	$I_{OH} = -5\text{ mA}$	25°C		4.9			
		Full range		4.7			
$V_{OL}$ Low-level output voltage	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 500\ \mu\text{A}$	25°C		0.01		V	
	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 5\text{ mA}$	25°C		0.1			
		Full range			0.3		
$A_{VD}$ Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$ , $V_O = 1\text{ V to }4\text{ V}$ , $R_L = 1\text{ k}\Omega$ , See Note 4	25°C	200	1000		V/mV	
		Full range	200				
$R_{I(D)}$ Differential input resistance		25°C		10		$\text{k}\Omega$	
$R_L$ Input resistance	See Note 4	25°C		$10^{12}$		$\Omega$	
$C_L$ Common-mode input capacitance	$f = 10\text{ kHz}$ , P package	25°C		8		$\text{pF}$	
$Z_O$ Closed-loop output impedance	$A_V = 10$ , $f = 100\text{ kHz}$	25°C		1		$\Omega$	
CMRR Common-mode rejection ratio	$V_{IC} = 0\text{ to }2.7\text{ V}$ , $V_O = 2.5\text{ V}$ , $R_S = 1\text{ k}\Omega$	25°C	90	100		dB	
		Full range	85				
$k_{SVR}$ Supply-voltage rejection ratio ( $\Delta V_{DD} \pm / \Delta V_{IO}$ )	$V_{DD} = 4\text{ V to }6\text{ V}$ , $V_{IC} = 0$ , No load	25°C	90	100		dB	
		Full range	90				
$I_{DD}$ Supply current	$V_O = 2.5\text{ V}$ , No load	TLC4501/A	25°C	1	1.5	mA	
			Full range		2		
		TLC4502/A	25°C	2.5	3.5		
			Full range		4		
$V_{IT(CAL)}$ Calibration input threshold voltage		Full range	4			V	

† Full range is 0°C to 70°C.

NOTE 4:  $R_L$  and  $C_L$  values are referenced to 2.5 V.



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operating characteristics,  $V_{DD} = 5\text{ V}$

PARAMETER		TEST CONDITIONS		$T_A^\dagger$	TLC450xC, TLC450xAC			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	$V_O = 0.5\text{ V to }2.5\text{ V}, C_L = 100\text{ pF}$		25°C	1.5	2.5		$\text{V}/\mu\text{s}$
				Full range	1			$\text{V}/\mu\text{s}$
$V_n$	Equivalent input noise voltage	f = 10 Hz		25°C	70			$\text{nV}/\sqrt{\text{Hz}}$
		f = 1 kHz		25°C	12			
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	f = 0.1 to 1 Hz		25°C	1			$\mu\text{V}$
		f = 0.1 to 10 Hz		25°C	1.5			
$I_n$	Equivalent input noise current			25°C	0.6			$\text{fA}/\sqrt{\text{Hz}}$
THD + N	Total harmonic distortion plus noise	$V_O = 0.5\text{ V to }2.5\text{ V},$ f = 10 kHz, $R_L = 1\text{ k}\Omega,$ $C_L = 100\text{ pF}$		$A_V = 1$	25°C	0.02%		
				$A_V = 10$	25°C	0.08%		
				$A_V = 100$	25°C	0.55%		
Gain-bandwidth product		f = 10 kHz, $C_L = 100\text{ pF}$	$R_L = 1\text{ k}\Omega,$	25°C	4.7			MHz
$B_{OM}$	Maximum output swing bandwidth	$V_{O(PP)} = 2\text{ V},$ $R_L = 1\text{ k}\Omega,$	$A_V = 1,$ $C_L = 100\text{ pF}$	25°C	1			MHz
$t_s$	Settling time	$A_V = -1,$ Step = 0.5 V to 2.5 V, $R_L = 1\text{ k}\Omega,$ $C_L = 100\text{ pF}$		to 0.1%	25°C	1.6		$\mu\text{s}$
				to 0.01%	25°C	2.2		
$\phi_m$	Phase margin at unity gain	$R_L = 1\text{ k}\Omega,$	$C_L = 100\text{ pF}$	25°C	74			
Calibration time				25°C	300			ms

$^\dagger$  Full range is 0°C to 70°C.

NOTE 4:  $R_L$  and  $C_L$  values are referenced to 2.5 V.



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electrical characteristics at specified free-air temperature,  $V_{DD} = 5\text{ V}$ ,  $GND = 0$  (unless otherwise noted)

PARAMETER	TEST CONDITIONS	$T_A$ †	TLC450xI			UNIT	
			MIN	TYP	MAX		
$V_{IO}$ Input offset voltage	$V_{DD} = \pm 2.5\text{ V}$ , $V_O = 0$ , $V_{IC} = 0$ , $R_S = 50\ \Omega$	Full range	TLC4501	-80	10	80	$\mu\text{V}$
			TLC4501A	-40	10	40	
			TLC4502	-100	10	100	
			TLC4502A	-50	10	50	
$\alpha_{VIO}$ Temperature coefficient of input offset voltage		Full range		1		$\mu\text{V}/^\circ\text{C}$	
$I_{IO}$ Input offset current	$V_{DD} = \pm 2.5\text{ V}$ , $V_O = 0$ , $V_{IC} = 0$ , $R_S = 50\ \Omega$	25°C		1	60	$\text{pA}$	
		-40°C to 85°C			500	$\text{pA}$	
		Full range			5	$\text{nA}$	
$I_{IB}$ Input bias current	$V_{DD} = \pm 2.5\text{ V}$ , $V_O = 0$ , $V_{IC} = 0$ , $R_S = 50\ \Omega$	25°C		1	60	$\text{pA}$	
		-40°C to 85°C			500	$\text{pA}$	
		Full range			10	$\text{nA}$	
$V_{OH}$ High-level output voltage	$I_{OH} = -500\ \mu\text{A}$	25°C		4.99		$\text{V}$	
	$I_{OH} = -5\text{ mA}$	25°C		4.9			
		Full range		4.7			
$V_{OL}$ Low-level output voltage	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 500\ \mu\text{A}$	25°C		0.01		$\text{V}$	
	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 5\text{ mA}$	25°C		0.1			
		Full range		0.3			
$A_{VD}$ Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$ , $V_O = 1\text{ V to }4\text{ V}$ , $R_L = 1\text{ k}\Omega$ , See Note 4	25°C	200	1000		$\text{V/mV}$	
		Full range	200				
$R_{I(D)}$ Differential input resistance		25°C		10		$\text{k}\Omega$	
$R_L$ Input resistance	See Note 4	25°C		$10^{12}$		$\Omega$	
$C_L$ Common-mode input capacitance	$f = 10\text{ kHz}$ , P package	25°C		8		$\text{pF}$	
$Z_O$ Closed-loop output impedance	$A_V = 10$ , $f = 100\text{ kHz}$	25°C		1		$\Omega$	
CMRR Common-mode rejection ratio	$V_{IC} = 0\text{ to }2.7\text{ V}$ , $V_O = 2.5\text{ V}$ , $R_S = 1\text{ k}\Omega$	25°C	90	100		$\text{dB}$	
		Full range	85				
$k_{SVR}$ Supply-voltage rejection ratio ( $\Delta V_{DD} \pm / \Delta V_{IO}$ )	$V_{DD} = 4\text{ V to }6\text{ V}$ , $V_{IC} = 0$ , No load	25°C	90	100		$\text{dB}$	
		Full range	90				
$I_{DD}$ Supply current	$V_O = 2.5\text{ V}$ , No load	TLC4501/A	25°C	1	1.5	$\text{mA}$	
			Full range		2		
		TLC4502/A	25°C	2.5	3.5		
			Full range		4		
$V_{IT(CAL)}$ Calibration input threshold voltage		Full range	4			$\text{V}$	

† Full range is -40°C to 125°C.

NOTE 4:  $R_L$  and  $C_L$  values are referenced to 2.5 V.



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operating characteristics,  $V_{DD} = 5\text{ V}$

PARAMETER		TEST CONDITIONS		$T_A$ †	TLC450xI, TLC450xAI			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	$V_O = 0.5\text{ V to }2.5\text{ V}, C_L = 100\text{ pF}$		25°C	1.5	2.5		$V/\mu\text{s}$
				Full range	1			$V/\mu\text{s}$
$V_n$	Equivalent input noise voltage	$f = 10\text{ Hz}$		25°C	70		$nV/\sqrt{\text{Hz}}$	
		$f = 1\text{ kHz}$		25°C	12			
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ to }1\text{ Hz}$		25°C	1		$\mu\text{V}$	
		$f = 0.1\text{ to }10\text{ Hz}$		25°C	1.5			
$I_n$	Equivalent input noise current			25°C	0.6		$fA/\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise	$V_O = 0.5\text{ V to }2.5\text{ V},$ $f = 10\text{ kHz},$ $R_L = 1\text{ k}\Omega,$ $C_L = 100\text{ pF}$		$A_V = 1$	25°C	0.02%		
				$A_V = 10$	25°C	0.08%		
				$A_V = 100$	25°C	0.55%		
Gain-bandwidth product		$f = 10\text{ kHz},$ $C_L = 100\text{ pF}$	$R_L = 1\text{ k}\Omega,$	25°C	4.7		MHz	
$B_{OM}$	Maximum output swing bandwidth	$V_{O(PP)} = 2\text{ V},$ $R_L = 1\text{ k}\Omega,$	$A_V = 1,$ $C_L = 100\text{ pF}$	25°C	1		MHz	
$t_s$	Settling time	$A_V = -1,$ Step = $0.5\text{ V to }2.5\text{ V},$ $R_L = 1\text{ k}\Omega,$ $C_L = 100\text{ pF}$		to 0.1%	25°C	1.6		$\mu\text{s}$
				to 0.01%	25°C	2.2		
$\phi_m$	Phase margin at unity gain	$R_L = 1\text{ k}\Omega,$	$C_L = 100\text{ pF}$	25°C	74			
Calibration time				25°C	300		ms	

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ .

NOTE 4:  $R_L$  and  $C_L$  values are referenced to 2.5 V.

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electrical characteristics at specified free-air temperature,  $V_{DD} = 5\text{ V}$ ,  $GND = 0$  (unless otherwise noted)

PARAMETER	TEST CONDITIONS	$T_A$ †	TLC4502Q, TLC4502M			UNIT	
			MIN	TYP	MAX		
$V_{IO}$ Input offset voltage	$V_{DD} = \pm 2.5\text{ V}$ , $V_O = 0$ , $V_{IC} = 0$ , $R_S = 50\ \Omega$	TLC4502 TLC4502A	Full range	-100 -50	10 10	100 50	$\mu\text{V}$
$\alpha_{VIO}$ Temperature coefficient of input offset voltage			Full range		1		$\mu\text{V}/^\circ\text{C}$
$I_{IO}$ Input offset current	$V_{DD} = \pm 2.5\text{ V}$ , $V_O = 0$ , $V_{IC} = 0$ , $R_S = 50\ \Omega$		25°C		1	60	nA
			125°C			5	
$I_{IB}$ Input bias current			25°C		1	60	nA
			125°C			10	
$V_{OH}$ High-level output voltage	$I_{OH} = -500\ \mu\text{A}$		25°C			4.99	V
	$I_{OH} = -5\text{ mA}$		25°C			4.9	
			Full range			4.7	
$V_{OL}$ Low-level output voltage	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 500\ \mu\text{A}$		25°C			0.01	V
	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 5\text{ mA}$		25°C			0.1	
			Full range			0.3	
$A_{VD}$ Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$ , $V_O = 1\text{ V to }4\text{ V}$ , $R_L = 1\text{ k}\Omega$ , See Note 4		25°C	200	1000		V/mV
			Full range	200			
$R_{I(D)}$ Differential input resistance			25°C		10		k $\Omega$
$R_L$ Input resistance	See Note 4		25°C		10 <sup>12</sup>		$\Omega$
$C_L$ Common-mode input capacitance	$f = 10\text{ kHz}$ , P package		25°C		8		pF
$z_O$ Closed-loop output impedance	$A_V = 10$ , $f = 100\text{ kHz}$		25°C		1		$\Omega$
$CMRR$ Common-mode rejection ratio	$V_{IC} = 0\text{ to }2.7\text{ V}$ , $V_O = 2.5\text{ V}$ , $R_S = 1\text{ k}\Omega$		25°C	90	100		dB
			Full range	85			
$k_{SVR}$ Supply-voltage rejection ratio ( $\Delta V_{DD} \pm / \Delta V_{IO}$ )	$V_{DD} = 4\text{ V to }6\text{ V}$ , $V_{IC} = V_{DD} / 2$ , No load		25°C	90	100		dB
			Full range	90			
$I_{DD}$ Supply current	$V_O = 2.5\text{ V}$ , No load		25°C		2.5	3.5	mA
			Full range			4	
$V_{IT(CAL)}$ Calibration input threshold voltage			Full range	4			V

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for Q suffix,  $-55^\circ\text{C}$  to  $125^\circ\text{C}$  for M suffix.

NOTE 4:  $R_L$  and  $C_L$  values are referenced to 2.5 V.





**TLC4501, TLC4501A, TLC4502, TLC4502A**  
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operating characteristics,  $V_{DD} = 5\text{ V}$

PARAMETER		TEST CONDITIONS		$T_A$ †	TLC4502Q, TLC4502M, TLC4502AQ, TLC4502AM			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	$V_O = 0.5\text{ V to }2.5\text{ V},$ See Note 4		$C_L = 100\text{ pF}$	25°C	1.5	2.5	V/ $\mu\text{s}$
					Full range	1		V/ $\mu\text{s}$
$V_n$	Equivalent input noise voltage	$f = 10\text{ Hz}$		25°C	70		nV/ $\sqrt{\text{Hz}}$	
		$f = 1\text{ kHz}$		25°C	12			
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ to }1\text{ Hz}$		25°C	1		$\mu\text{V}$	
		$f = 0.1\text{ to }10\text{ Hz}$		25°C	1.5			
$I_n$	Equivalent input noise current			25°C	0.6		fA/ $\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise	$V_O = 0.5\text{ V to }2.5\text{ V},$ $f = 10\text{ kHz},$ $R_L = 1\text{ k}\Omega,$ $C_L = 100\text{ pF}$		$A_V = 1$	25°C	0.02%		
				$A_V = 10$	25°C	0.08%		
				$A_V = 100$	25°C	0.55%		
Gain-bandwidth product		$f = 10\text{ kHz},$ $C_L = 100\text{ pF}$	$R_L = 1\text{ k}\Omega,$	25°C	4.7		MHz	
BOM	Maximum output swing bandwidth	$V_{O(PP)} = 2\text{ V},$ $R_L = 1\text{ k}\Omega,$	$A_V = 1,$ $C_L = 100\text{ pF}$	25°C	1		MHz	
$t_s$	Settling time	$A_V = -1,$ Step = 0.5 V to 2.5 V, $R_L = 1\text{ k}\Omega,$ $C_L = 100\text{ pF}$		to 0.1%	25°C	1.6		$\mu\text{s}$
				to 0.01%	25°C	2.2		
$\phi_m$	Phase margin at unity gain	$R_L = 1\text{ k}\Omega,$	$C_L = 100\text{ pF}$	25°C	74			
Calibration time				25°C	300		ms	

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for Q suffix,  $-55^\circ\text{C}$  to  $125^\circ\text{C}$  for M suffix.

NOTE 4:  $R_L$  and  $C_L$  values are referenced to 2.5 V.



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**TYPICAL CHARACTERISTICS**

**Table of Graphs**

		<b>FIGURE</b>	
$V_{IO}$	Input offset voltage	Distribution	2, 3, 4
		vs Common-mode input voltage	5
$\alpha V_{IO}$	Input offset voltage temperature coefficient	Distribution	6, 7
$V_{OH}$	High-level output voltage	vs High-level output current	8
$V_{OL}$	Low-level output voltage	vs Low-level output current	9
$V_{O(PP)}$	Maximum peak-to-peak output voltage	vs Frequency	10
$I_{OS}$	Short-circuit output current	vs Free-air temperature	11
$V_O$	Output voltage	vs Differential input voltage	12
$A_{VD}$	Large-signal differential voltage amplification	vs Free-air temperature	13
		vs Frequency	14
$z_o$	Output impedance	vs Frequency	15
CMRR	Common-mode rejection ratio	vs Frequency	16
		vs Free-air temperature	17
SR	Slew rate	vs Load capacitance	18
		vs Free-air temperature	19
	Inverting large-signal pulse response		20
	Voltage-follower large-signal pulse response		21
	Inverting small-signal pulse response		22
	Voltage-follower small-signal pulse response		23
$V_n$	Equivalent input noise voltage	vs Frequency	24
		Over a 10-second period	25
THD + N	Total harmonic distortion plus noise	vs Frequency	26
		Gain-bandwidth product	vs Free-air temperature
$\phi_m$	Phase margin	vs Load capacitance	28
		vs Frequency	14
		Gain margin	vs Load capacitance
PSRR	Power-supply rejection ratio	vs Free-air temperature	30
	Calibration time at $-40^{\circ}\text{C}$		31
	Calibration time at $25^{\circ}\text{C}$		32
	Calibration time at $85^{\circ}\text{C}$		33
	Calibration time at $125^{\circ}\text{C}$		34



TYPICAL CHARACTERISTICS

DISTRIBUTION OF TLC4502 INPUT  
 OFFSET VOLTAGE

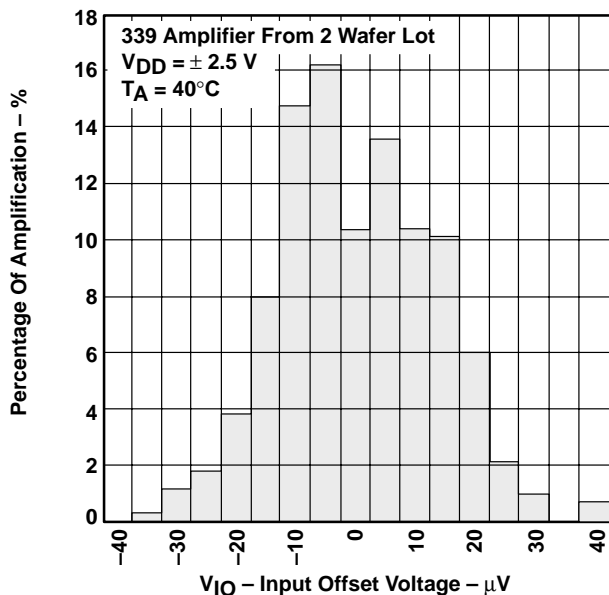


Figure 2

DISTRIBUTION OF TLC4502 INPUT  
 OFFSET VOLTAGE

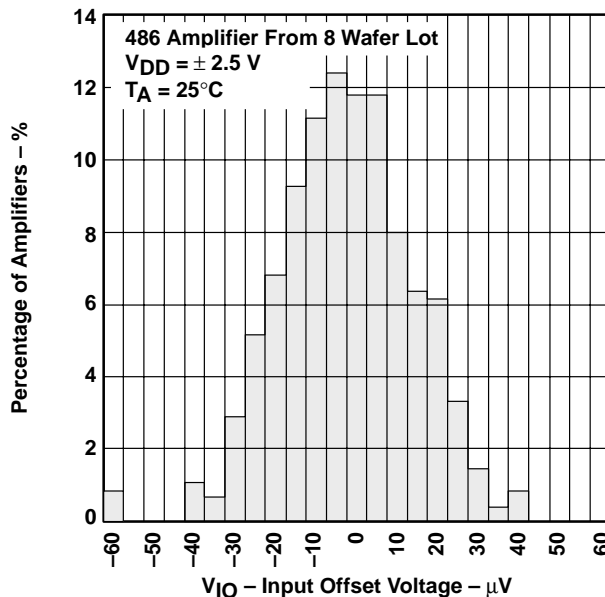


Figure 3

DISTRIBUTION OF TLC4502 INPUT  
 OFFSET VOLTAGE

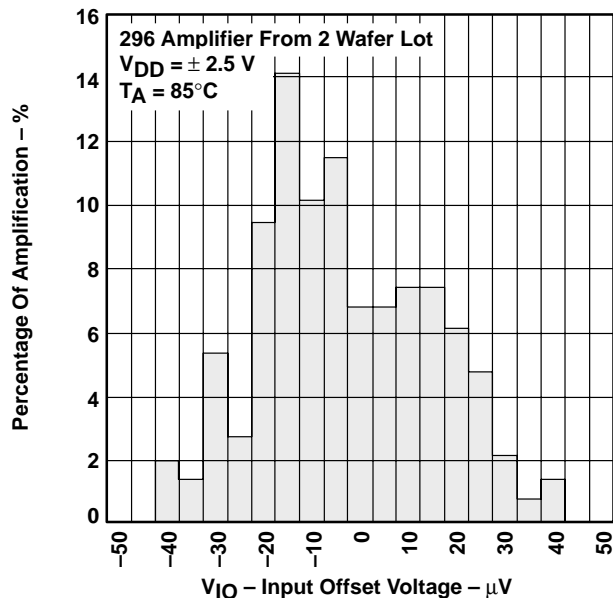


Figure 4

INPUT OFFSET VOLTAGE  
 vs  
 COMMON-MODE INPUT VOLTAGE

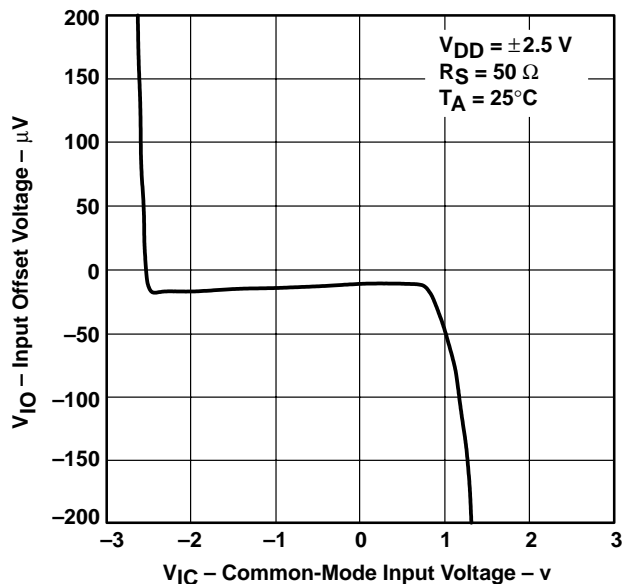


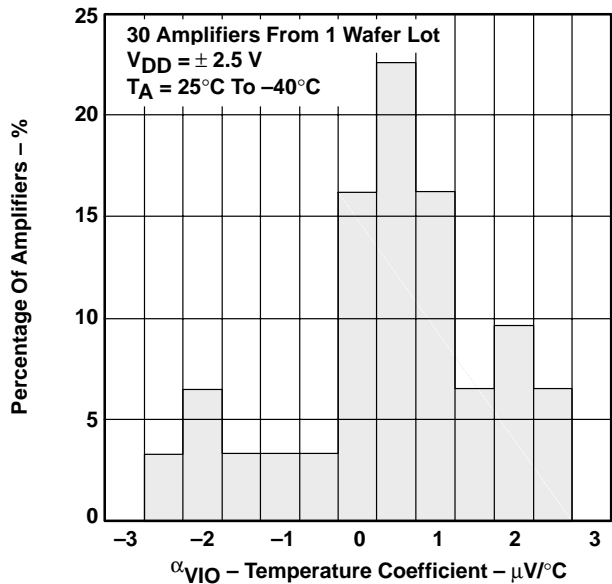
Figure 5

**TLC4501, TLC4501A, TLC4502, TLC4502A**  
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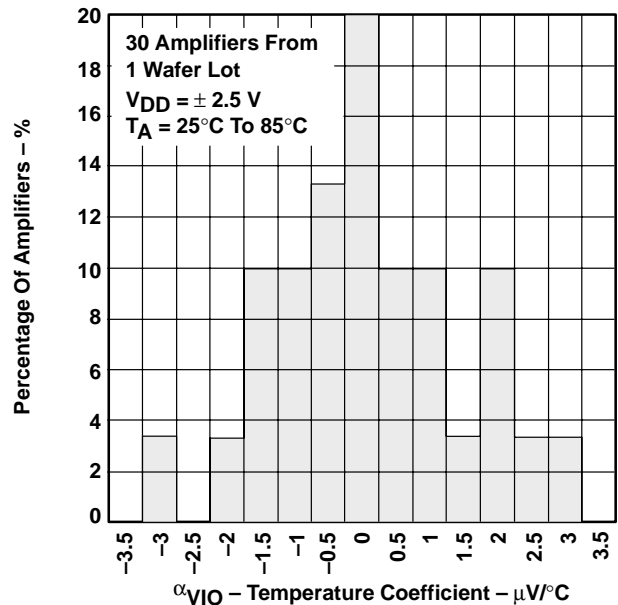
**TYPICAL CHARACTERISTICS**

**DISTRIBUTION OF TLC4502 INPUT OFFSET VOLTAGE TEMPERATURE COEFFICIENT**



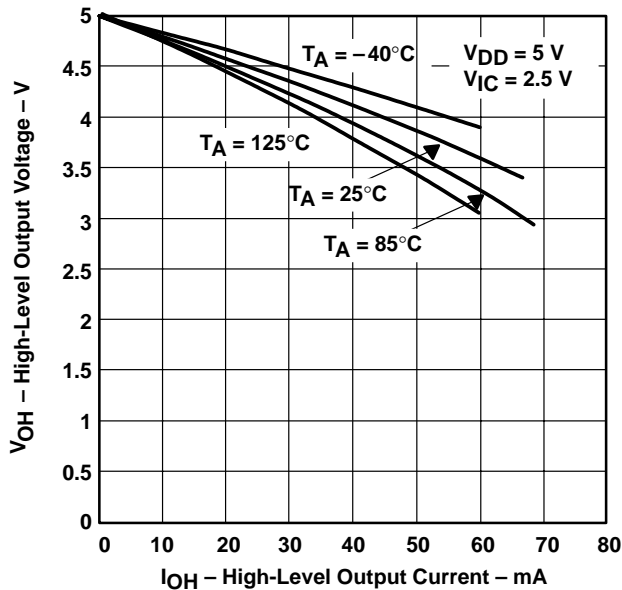
**Figure 6**

**DISTRIBUTION OF TLC4502 INPUT OFFSET VOLTAGE TEMPERATURE COEFFICIENT**



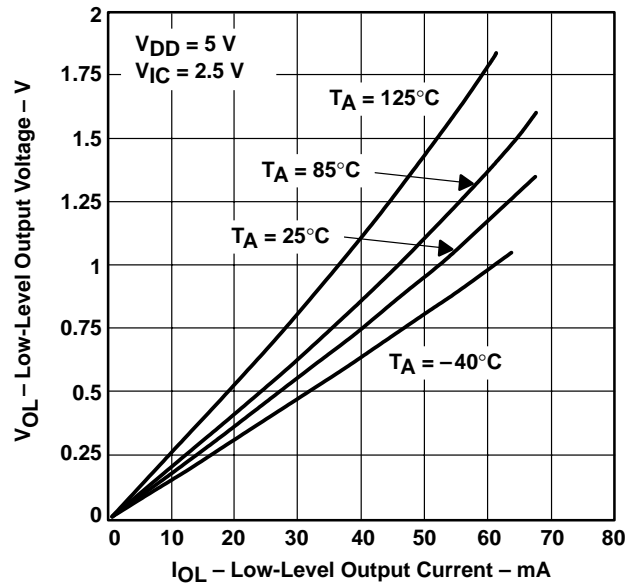
**Figure 7**

**HIGH-LEVEL OUTPUT VOLTAGE vs HIGH-LEVEL OUTPUT CURRENT**



**Figure 8**

**LOW-LEVEL OUTPUT VOLTAGE vs LOW-LEVEL OUTPUT CURRENT**



**Figure 9**



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TYPICAL CHARACTERISTICS

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE  
 VS  
 FREQUENCY

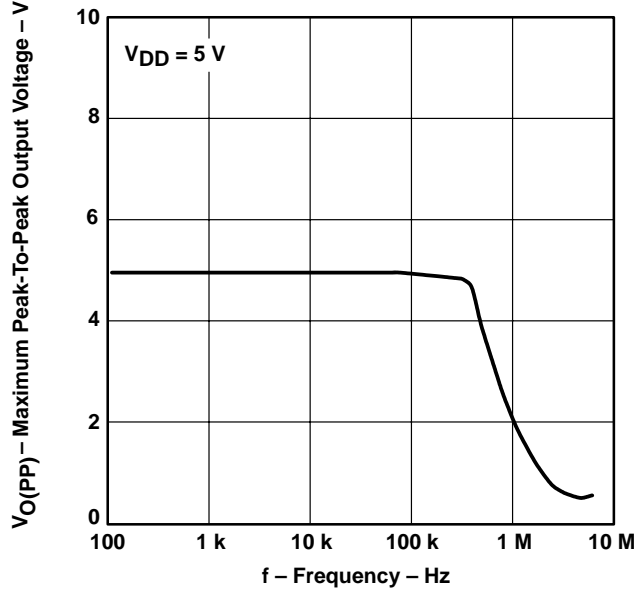


Figure 10

SHORT-CIRCUIT OUTPUT CURRENT  
 VS  
 FREE-AIR TEMPERATURE

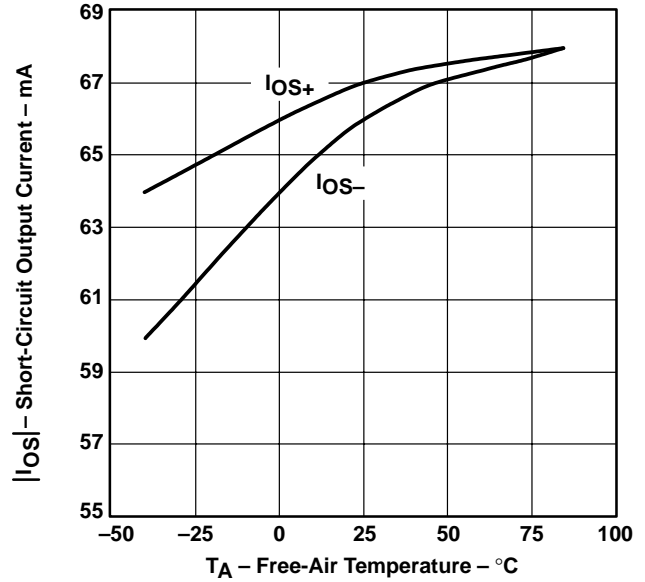


Figure 11

OUTPUT VOLTAGE  
 VS  
 DIFFERENTIAL INPUT VOLTAGE

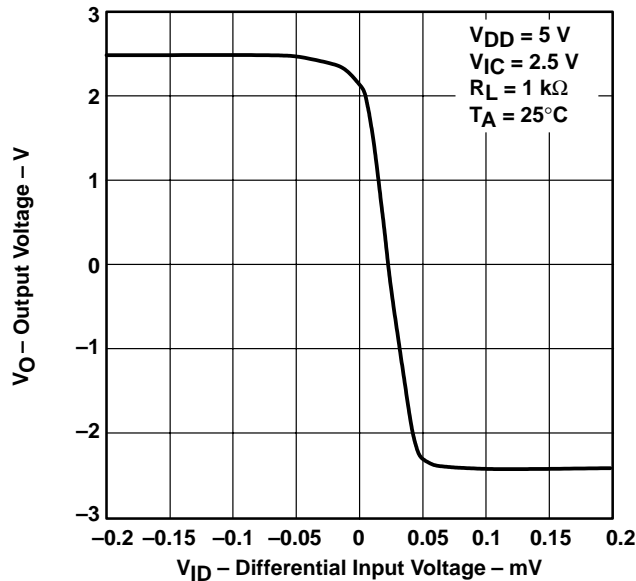


Figure 12

LARGE-SIGNAL DIFFERENTIAL  
 VOLTAGE AMPLIFICATION  
 VS  
 FREE-AIR TEMPERATURE

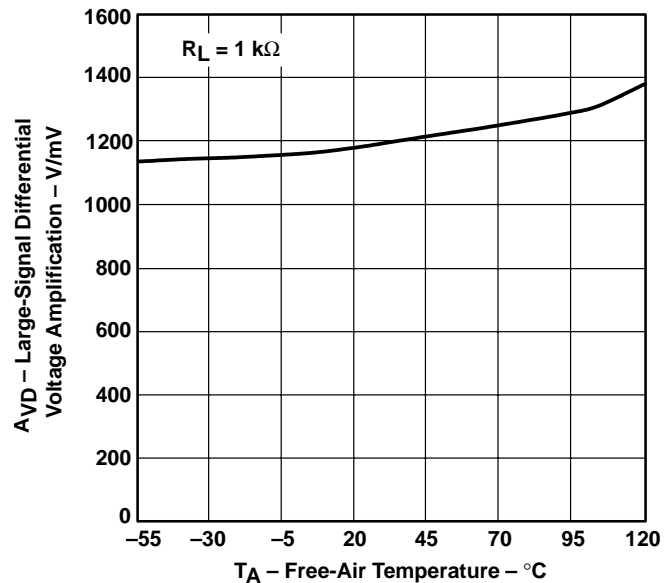


Figure 13

TYPICAL CHARACTERISTICS

LARGE-SIGNAL DIFFERENTIAL VOLTAGE  
 AMPLIFICATION AND PHASE MARGIN  
 vs  
 FREQUENCY

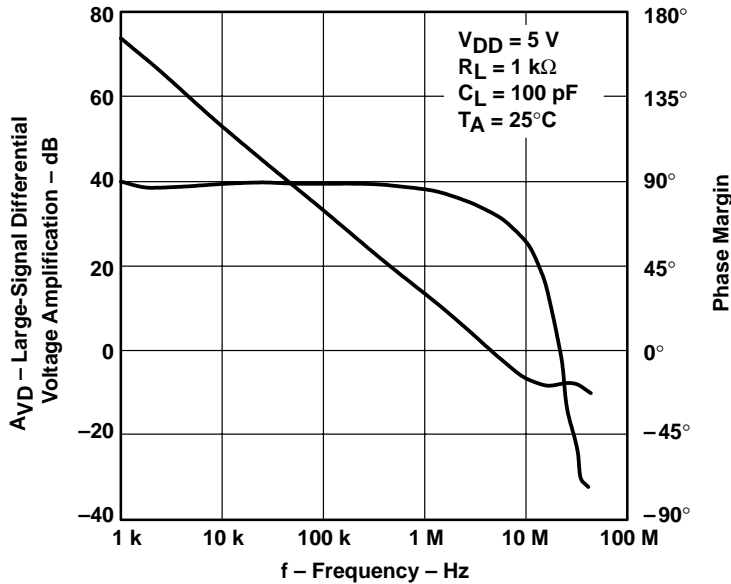


Figure 14

OUTPUT IMPEDANCE  
 vs  
 FREQUENCY

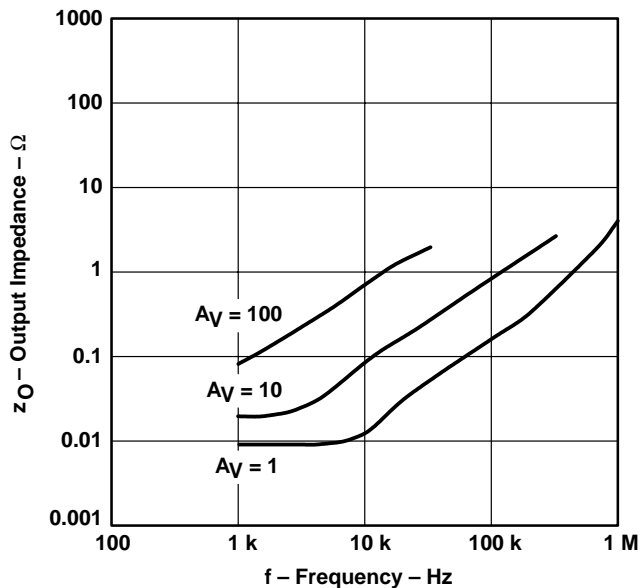


Figure 15

TYPICAL CHARACTERISTICS

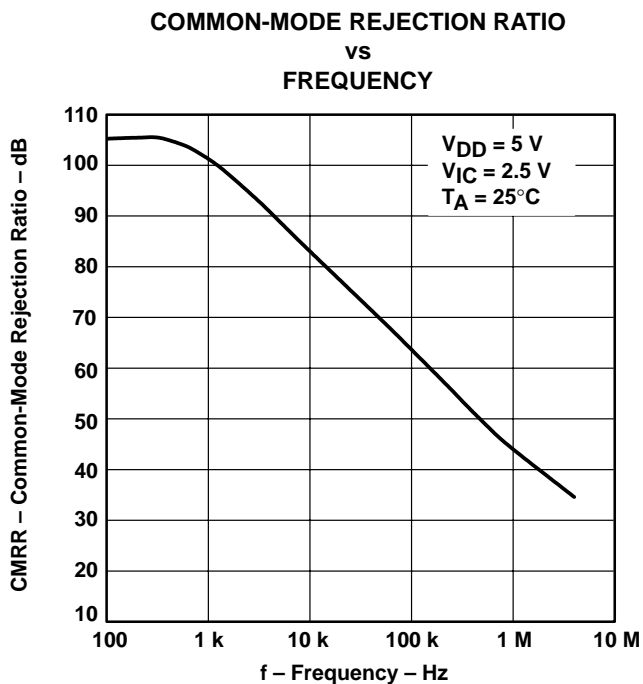


Figure 16

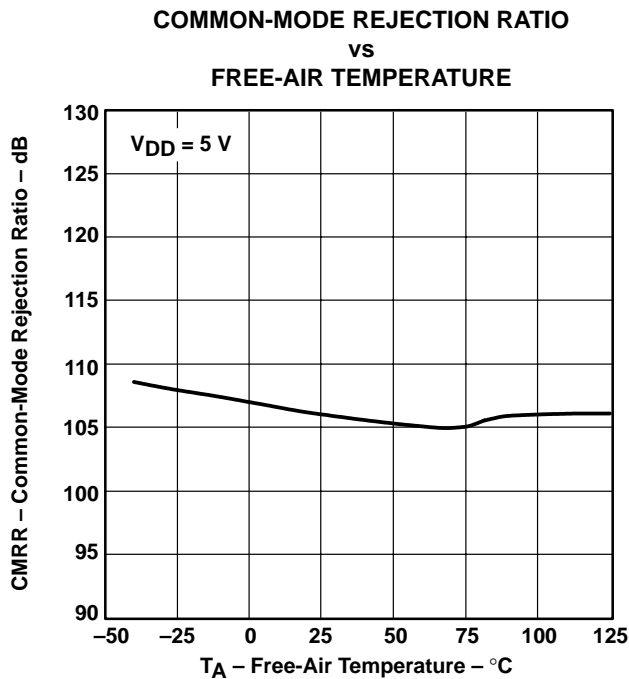


Figure 17

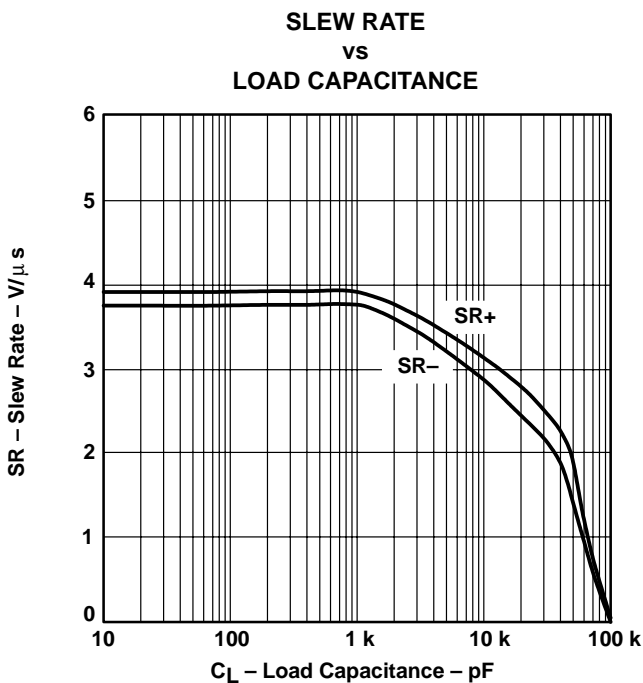


Figure 18

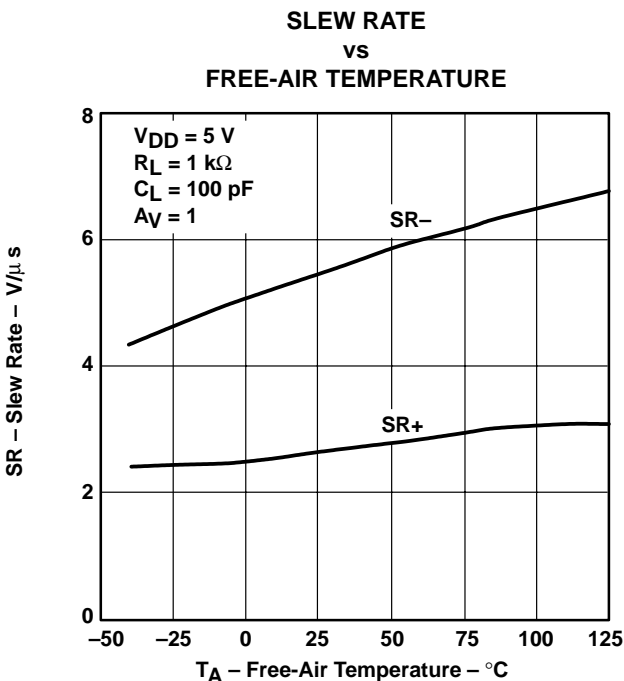


Figure 19

TYPICAL CHARACTERISTICS

INVERTING LARGE-SIGNAL PULSE RESPONSE

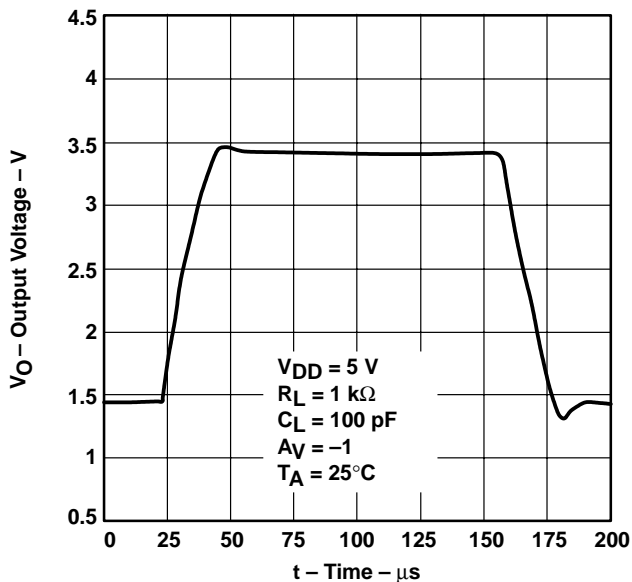


Figure 20

VOLTAGE-FOLLOWER LARGE-SIGNAL PULSE RESPONSE

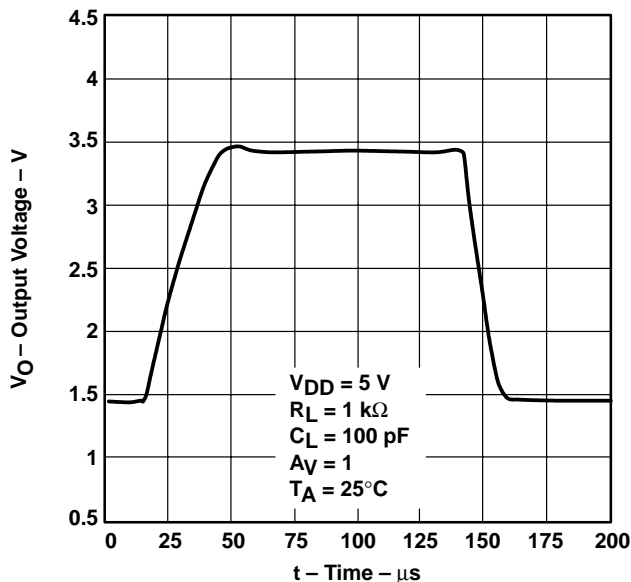


Figure 21

INVERTING SMALL-SIGNAL PULSE RESPONSE

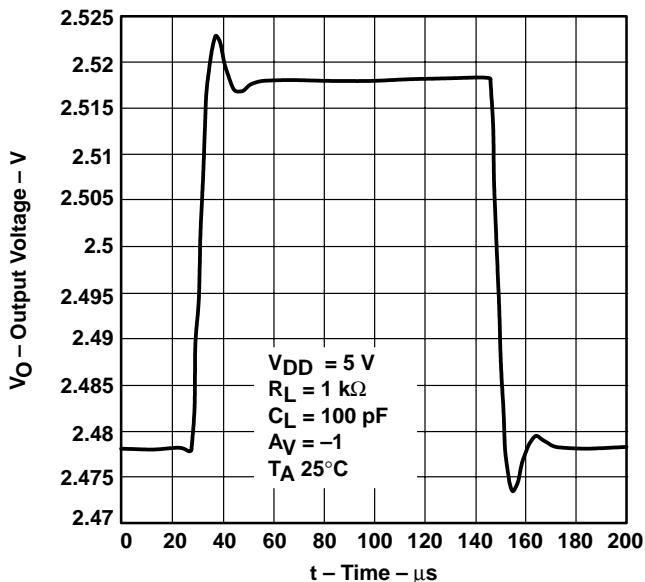


Figure 22

VOLTAGE-FOLLOWER SMALL-SIGNAL PULSE RESPONSE

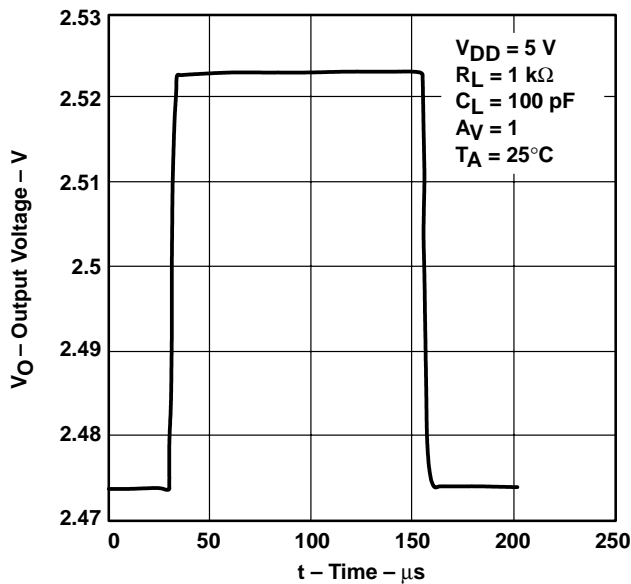


Figure 23



TYPICAL CHARACTERISTICS

EQUIVALENT INPUT NOISE VOLTAGE  
 vs  
 FREQUENCY

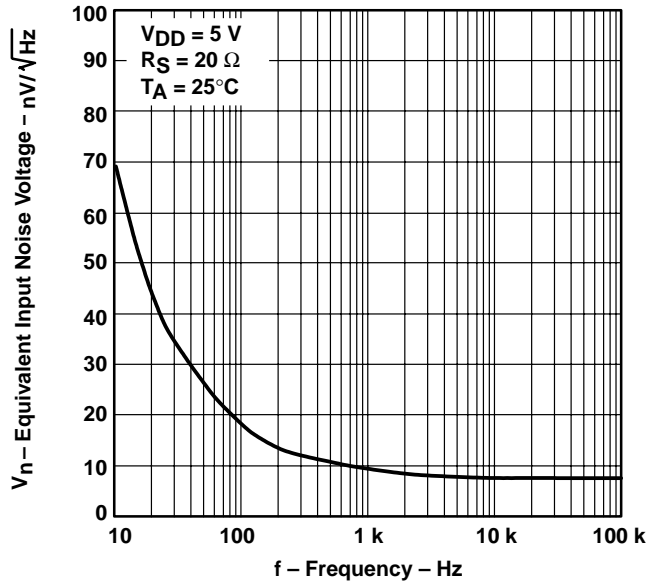


Figure 24

INPUT NOISE VOLTAGE OVER  
 A 10-SECOND PERIOD

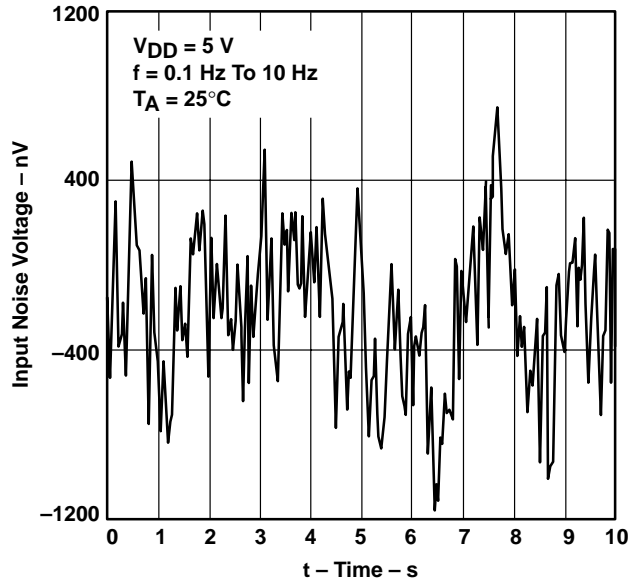


Figure 25

TOTAL HARMONIC DISTORTION PLUS NOISE  
 vs  
 FREQUENCY

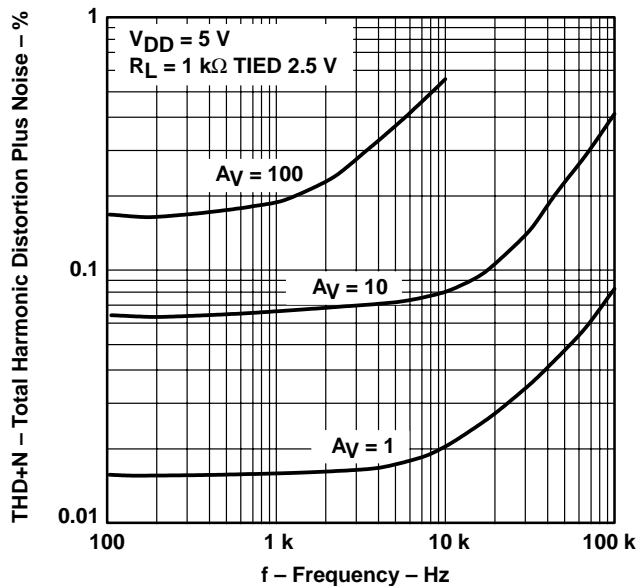


Figure 26

GAIN-BANDWIDTH PRODUCT  
 vs  
 FREE-AIR TEMPERATURE

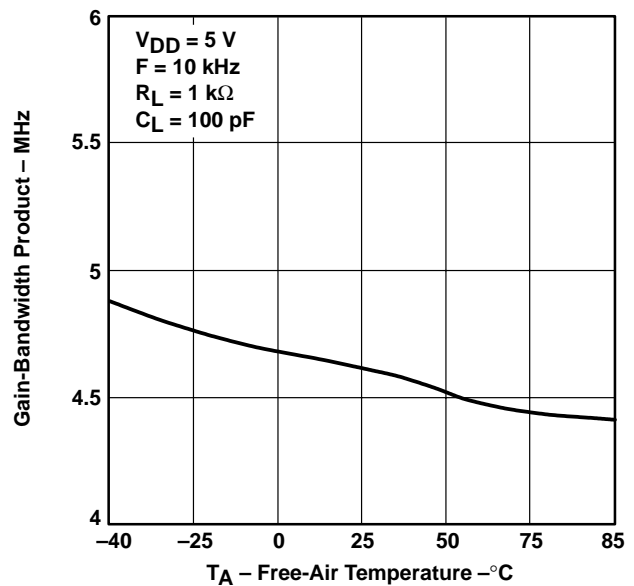


Figure 27

TYPICAL CHARACTERISTICS

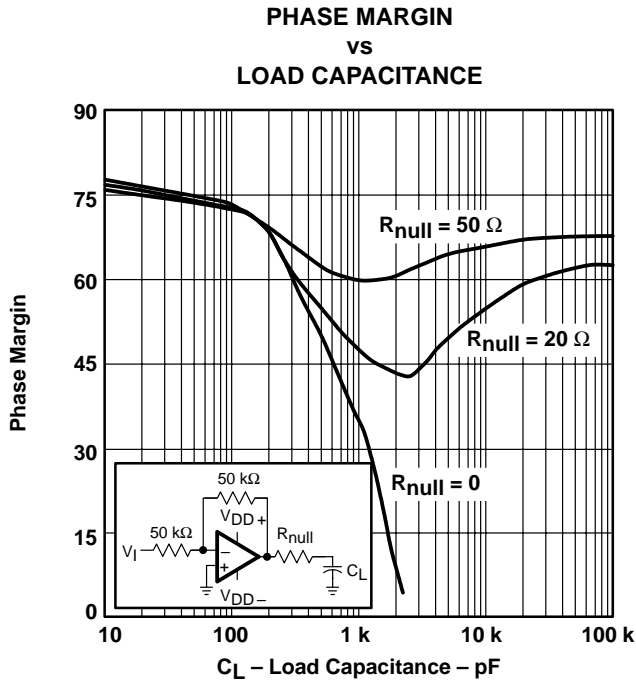


Figure 28

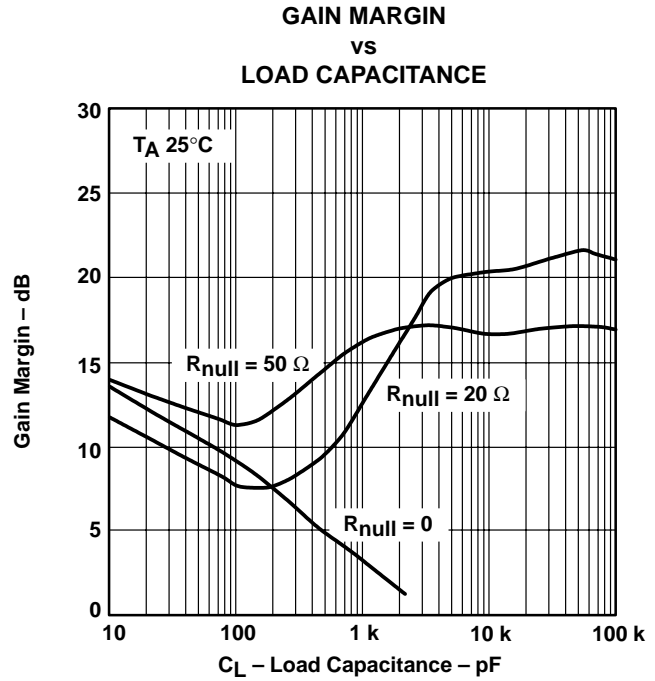


Figure 29

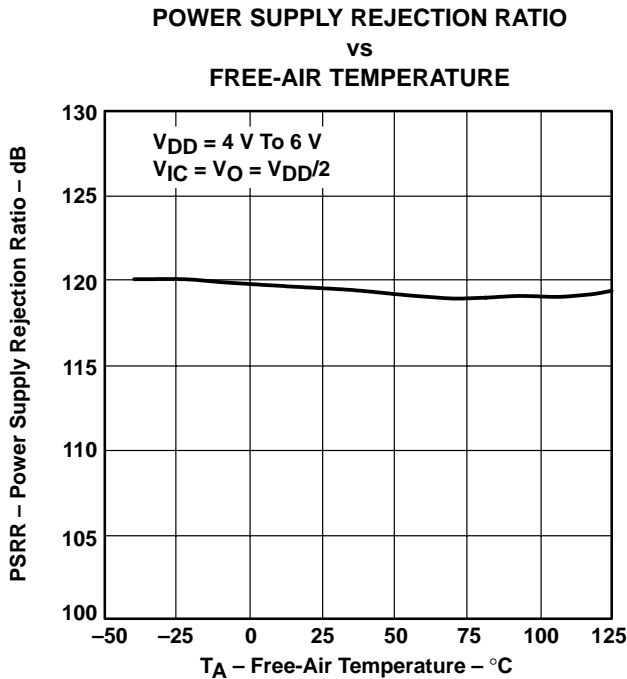


Figure 30

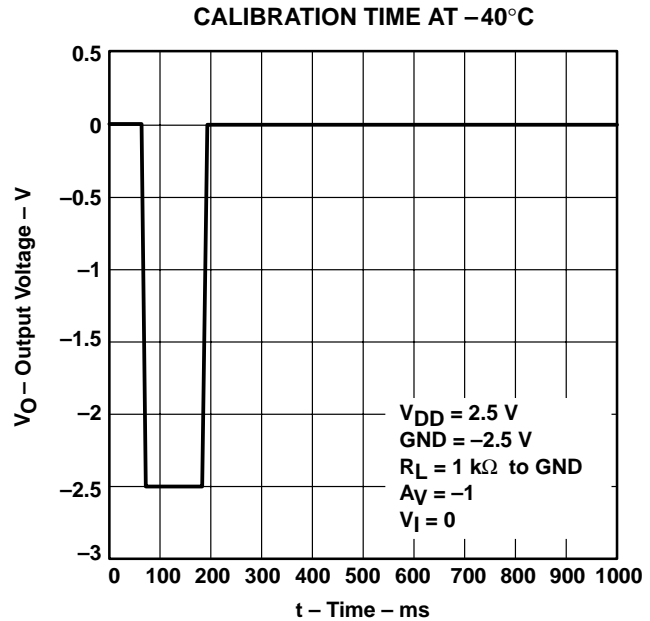


Figure 31

TYPICAL CHARACTERISTICS

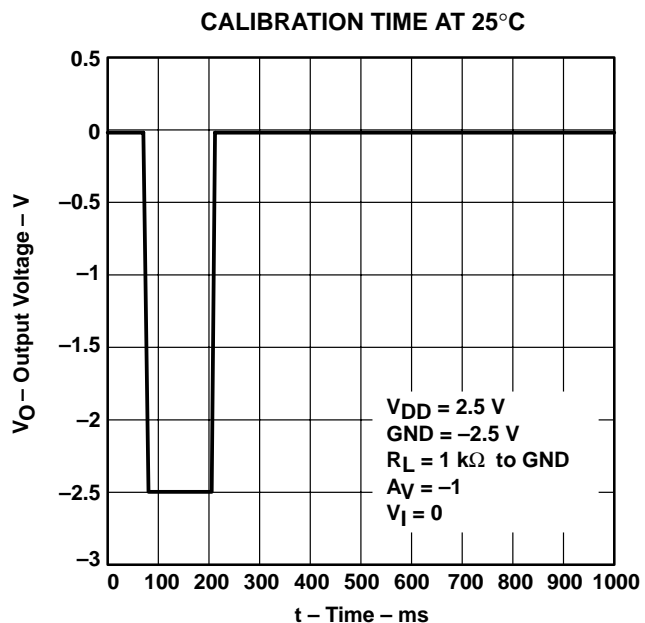


Figure 32

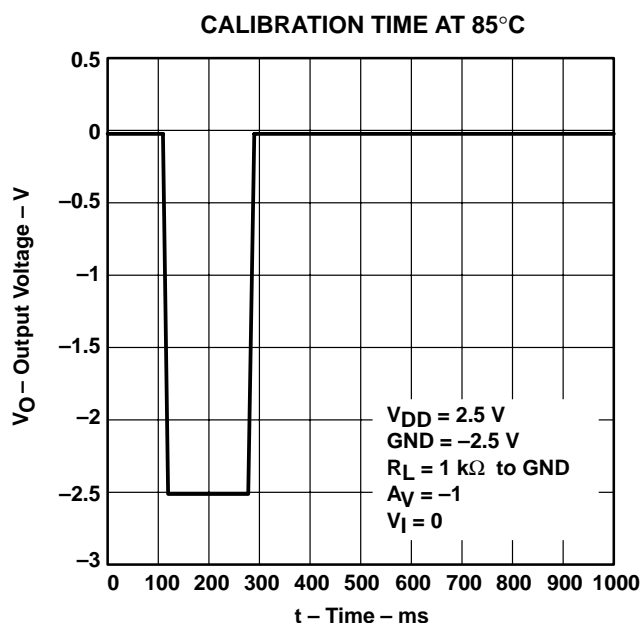


Figure 33

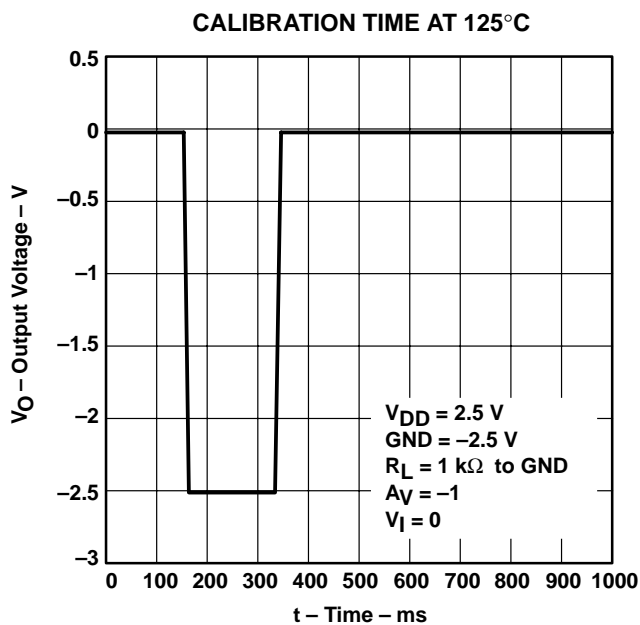


Figure 34

**TLC4501, TLC4501A, TLC4502, TLC4502A**  
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**APPLICATION INFORMATION**

- The TLC4502 is designed to operate with only a single 5-V power supply, have true differential inputs, and remain in the linear mode with an input common-mode voltage of 0.
- The TLC4502 has a standard dual-amplifier pinout, allowing for easy design upgrades.
- Large differential input voltages can be easily accommodated and, as input differential-voltage protection diodes are not needed, no large input currents result from large differential input voltage. Protection should be provided to prevent the input voltages from going negative more than  $-0.3\text{ V}$  at  $25^\circ\text{C}$ . An input clamp diode with a resistor to the device input terminal can be used for this purpose.
- For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor can be used from the output of the amplifier to ground. This increases the class-A bias current and prevents crossover distortion. Where the load is directly coupled, for example in dc applications, there is no crossover distortion.
- Capacitive loads, which are applied directly to the output of the amplifier, reduce the loop stability margin. Values of  $500\text{ pF}$  can be accommodated using the worst-case noninverting unity-gain connection. Resistive isolation should be considered when larger load capacitance must be driven by the amplifier.

The following typical application circuits emphasize operation on only a single power supply. When complementary power supplies are available, the TLC4502 can be used in all of the standard operational amplifier circuits. In general, introducing a pseudo-ground (a bias voltage of  $V_I/2$  like that generated by the TLE2426) allows operation above and below this value in a single-supply system. Many application circuits shown take advantage of the wide common-mode input-voltage range of the TLC4502, which includes ground. In most cases, input biasing is not required and input voltages that range to ground can easily be accommodated.

**description of calibration procedure**

To achieve high dc gain, large bandwidth, high CMRR and PSRR, as well as good output drive capability, the TLC4502 is built around a 3-stage topology: two gain stages, one rail-to-rail, and a class-AB output stage. A nested Miller topology is used for frequency compensation.

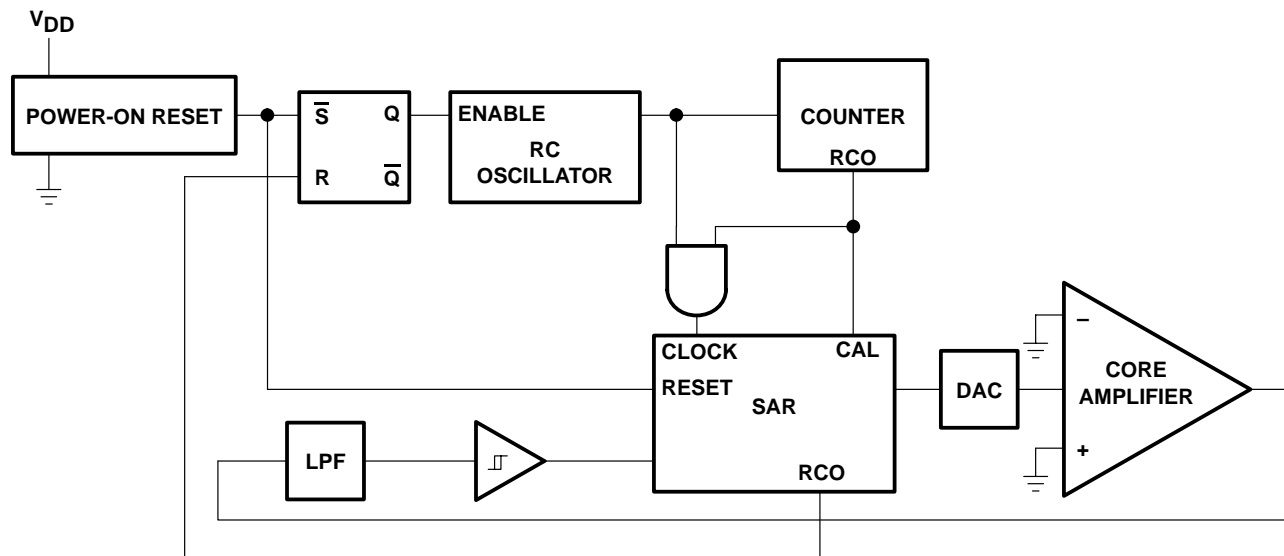
During the calibration procedure, the operational amplifier is removed from the signal path and both inputs are tied to GND. Figure 35 shows a block diagram of the amplifier during calibration mode.



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**Figure 35. Block Diagram During Calibration Mode**

The class AB output stage features rail-to-rail voltage swing and incorporates additional switches to put the output node into a high-impedance mode during the calibration cycle. Small-replica output transistors (matched to the main output transistors) provide the amplifier output signal for the calibration circuit. The TLC4502 also features built-in output short-circuit protection. The output current flowing through the main output transistors is continuously being sensed. If the current through either of these transistors exceeds the preset limit (60 mA – 70 mA) for more than about 1  $\mu$ s, the output transistors are shut down to approximately their quiescent operating point for approximately 5 ms. The device is then returned to normal operation. If the short circuit is still in place, it is detected in less than 1  $\mu$ s and the device is shut down for another 5 ms.

The offset cancellation uses a current-mode digital-to-analog converter (DAC), whose full-scale current allows for an adjustment of approximately  $\pm 5$  mV to the input offset voltage. The digital code producing the cancellation current is stored in the successive-approximation register (SAR).

During power up, when the offset cancellation procedure is initiated, an on-chip RC oscillator is activated to provide the timing of the successive-approximation algorithm. To prevent wide-band noise from interfering with the calibration procedure, an analog low-pass filter followed by a Schmitt trigger is used in the decision chain to implement an averaging process. Once the calibration procedure is complete, the RC oscillator is deactivated to reduce supply current and the associated noise.

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**APPLICATION INFORMATION**

The key operational-amplifier parameters CMRR, PSRR, and offset drift were optimized to achieve superior offset performance. The TLC4502 calibration DAC is implemented by a binary-weighted current array using a pseudo-R-2R MOSFET ladder architecture, which minimizes the silicon area required for the calibration circuitry, and thereby reduces the cost of the TLC4502.

Due to the performance (precision, PSRR, CMRR, gain, output drive, and ac performance) of the TLC4502, it is ideal for applications like:

- Data acquisition systems
- Medical equipment
- Portable digital scales
- Strain gauges
- Automotive sensors
- Digital audio circuits
- Industrial control applications

It is also ideal in circuits like:

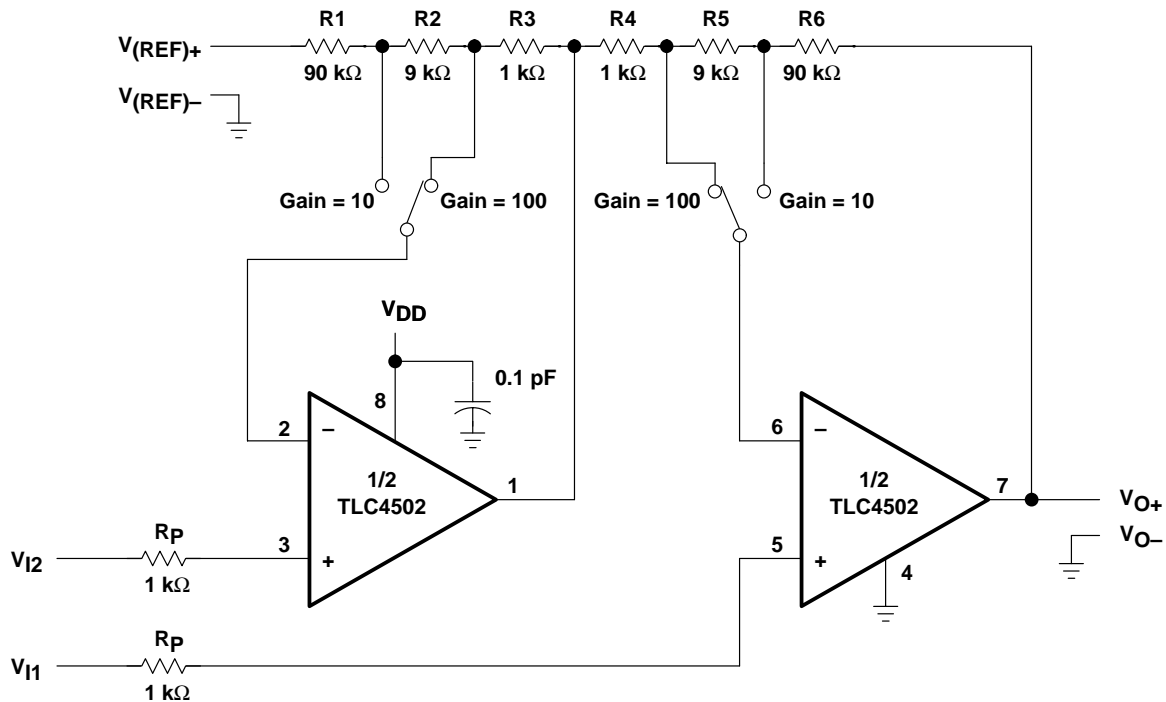
- A precision buffer for current-to-voltage converters, a/d buffers, or bridge applications
- High-impedance buffers or preamplifiers
- Long term integration
- Sample-and-hold circuits
- Peak detectors

The TLC4502 self-calibrating operational amplifier is manufactured using Texas instruments LinEPIC process technology and is available in an 8-pin SOIC (D) Package. 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 125°C. The M-suffix devices are characterized for operation from –55°C to 125°C.



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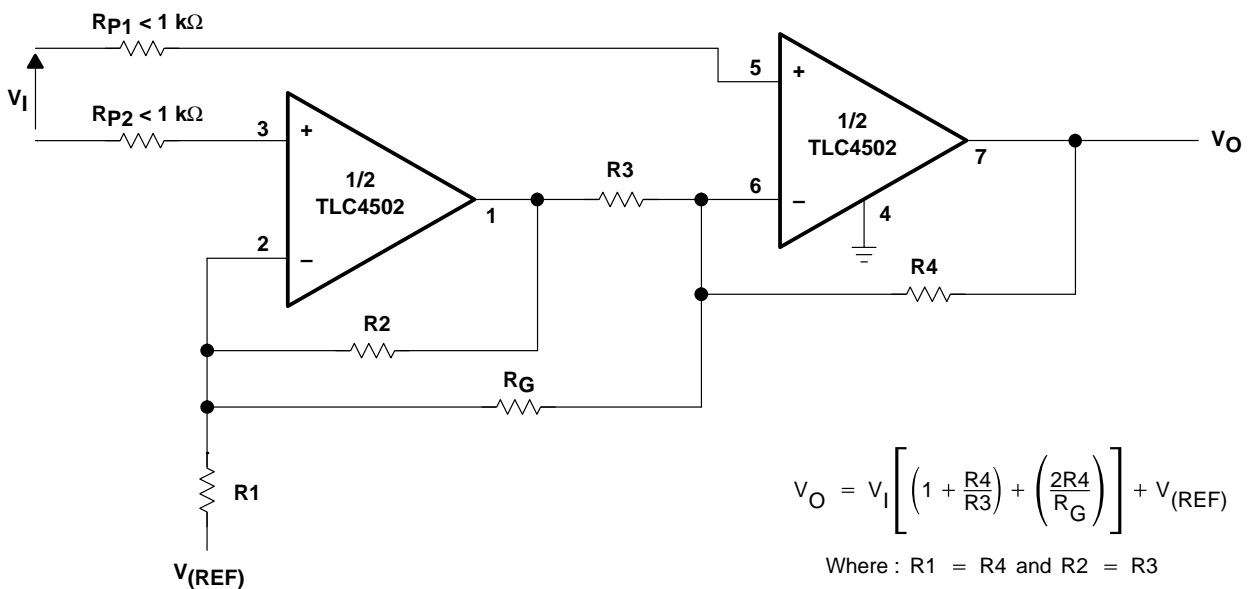
**APPLICATION INFORMATION**



$$\text{(Gain = 10)} \quad V_O = (V_{I1} - V_{I2}) \left( 1 + \frac{R_6}{R_4 + R_5} \right) + V_{(REF)} \quad \text{Where } R_1 = R_6, R_2 = R_5, \text{ and } R_3 = R_4$$

$$\text{(Gain = 100)} \quad V_O = (V_{I1} - V_{I2}) \left( 1 + \frac{R_5 + R_6}{R_4} \right) + V_{(REF)} \quad \text{Where } R_1 = R_6, R_2 = R_5, \text{ and } R_3 = R_4$$

**Figure 36. Single-Supply Programmable Instrumentation Amplifier Circuit**



$$V_O = V_I \left[ \left( 1 + \frac{R_4}{R_3} \right) + \left( \frac{2R_4}{R_G} \right) \right] + V_{(REF)}$$

Where :  $R_1 = R_4$  and  $R_2 = R_3$

**Figure 37. Two Operational-Amplifier Instrumentation Amplifier Circuit**

APPLICATION INFORMATION

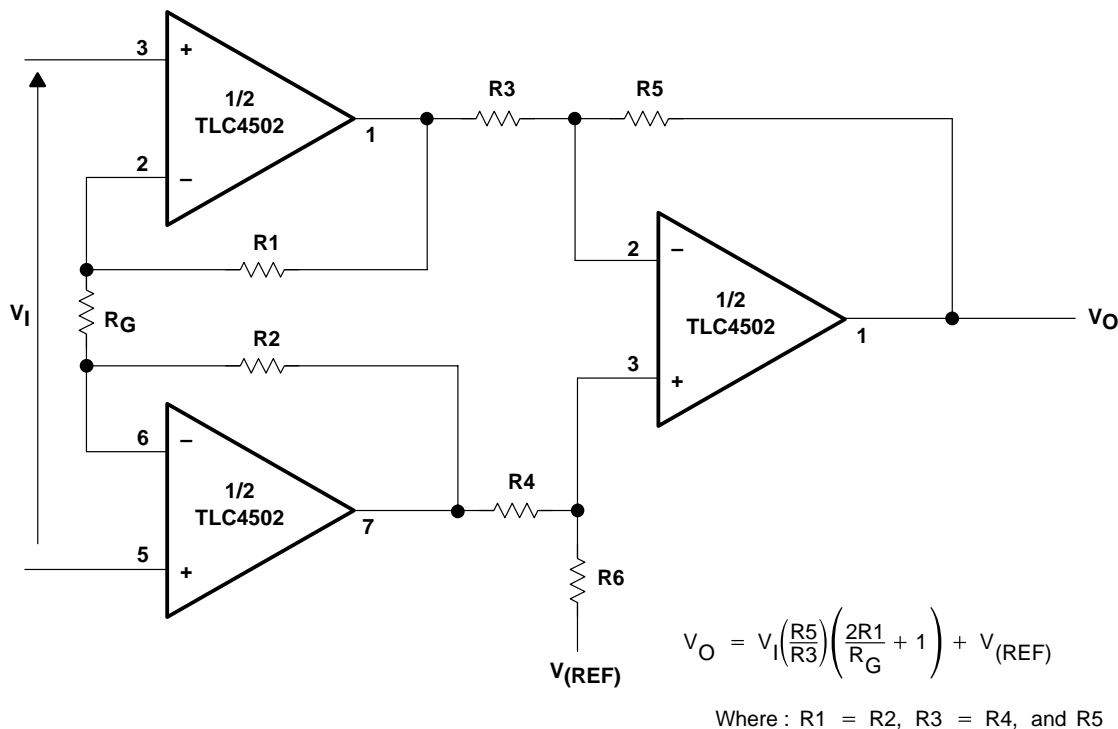


Figure 38. Three Operational-Amplifier Instrumentation Amplifier Circuit

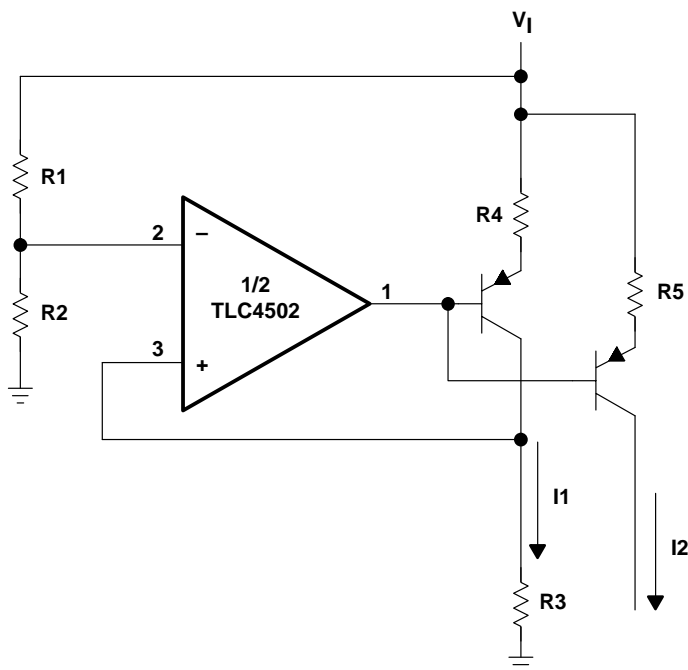
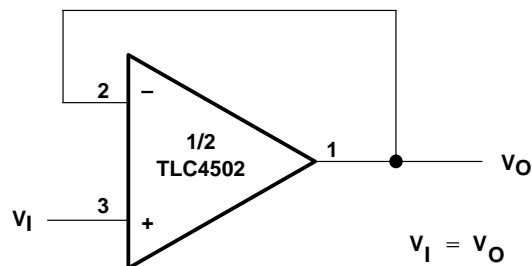


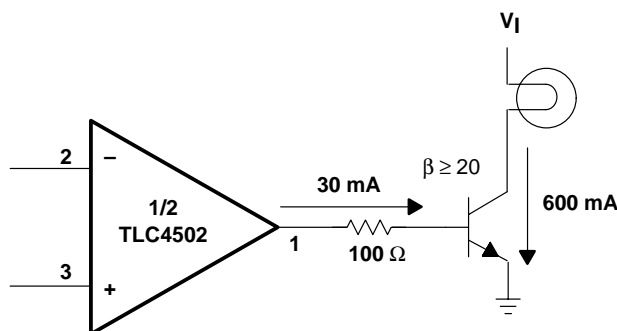
Figure 39. Fixed Current-Source Circuit



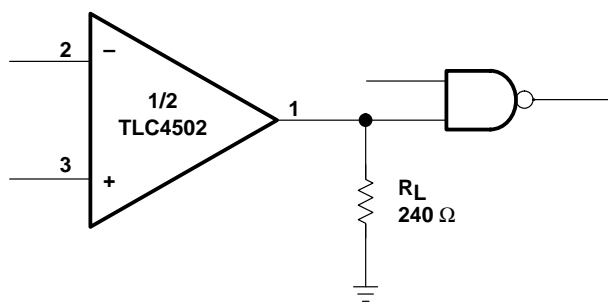
**APPLICATION INFORMATION**



**Figure 40. Voltage-Follower Circuit**



**Figure 41. Lamp-Driver Circuit**



**Figure 42. TTL-Driver Circuit**

APPLICATION INFORMATION

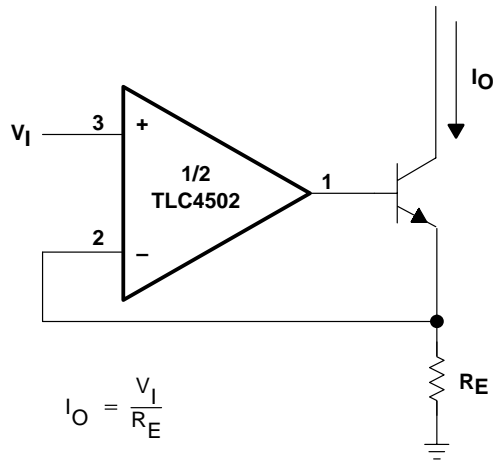


Figure 43. High-Compliance Current-Sink Circuit

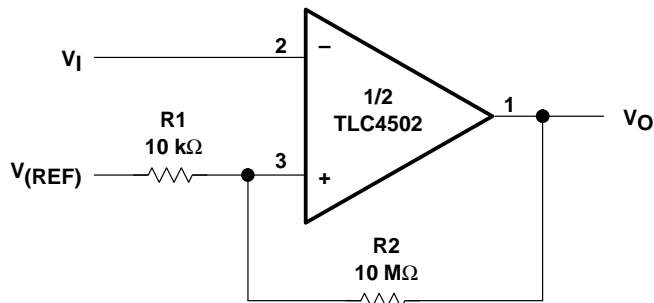


Figure 44. Comparator With Hysteresis Circuit

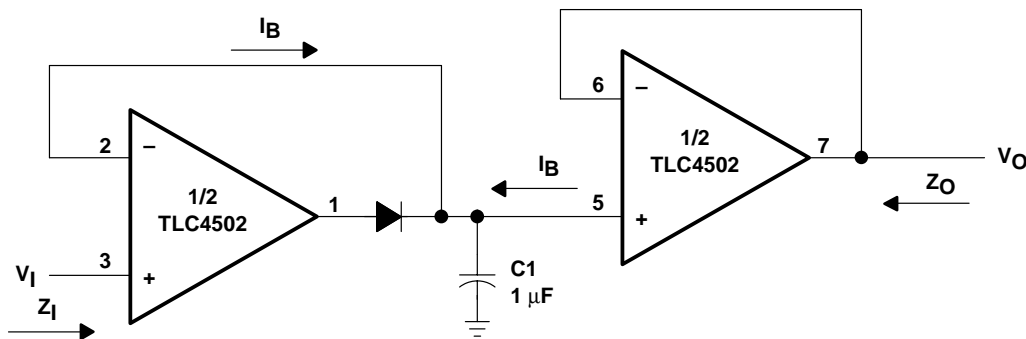


Figure 45. Low-Drift Detector Circuit

# TLC4501, TLC4501A, TLC4502, TLC4502A FAMILY OF SELF-CALIBRATING (Self-Cal™) PRECISION CMOS RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS

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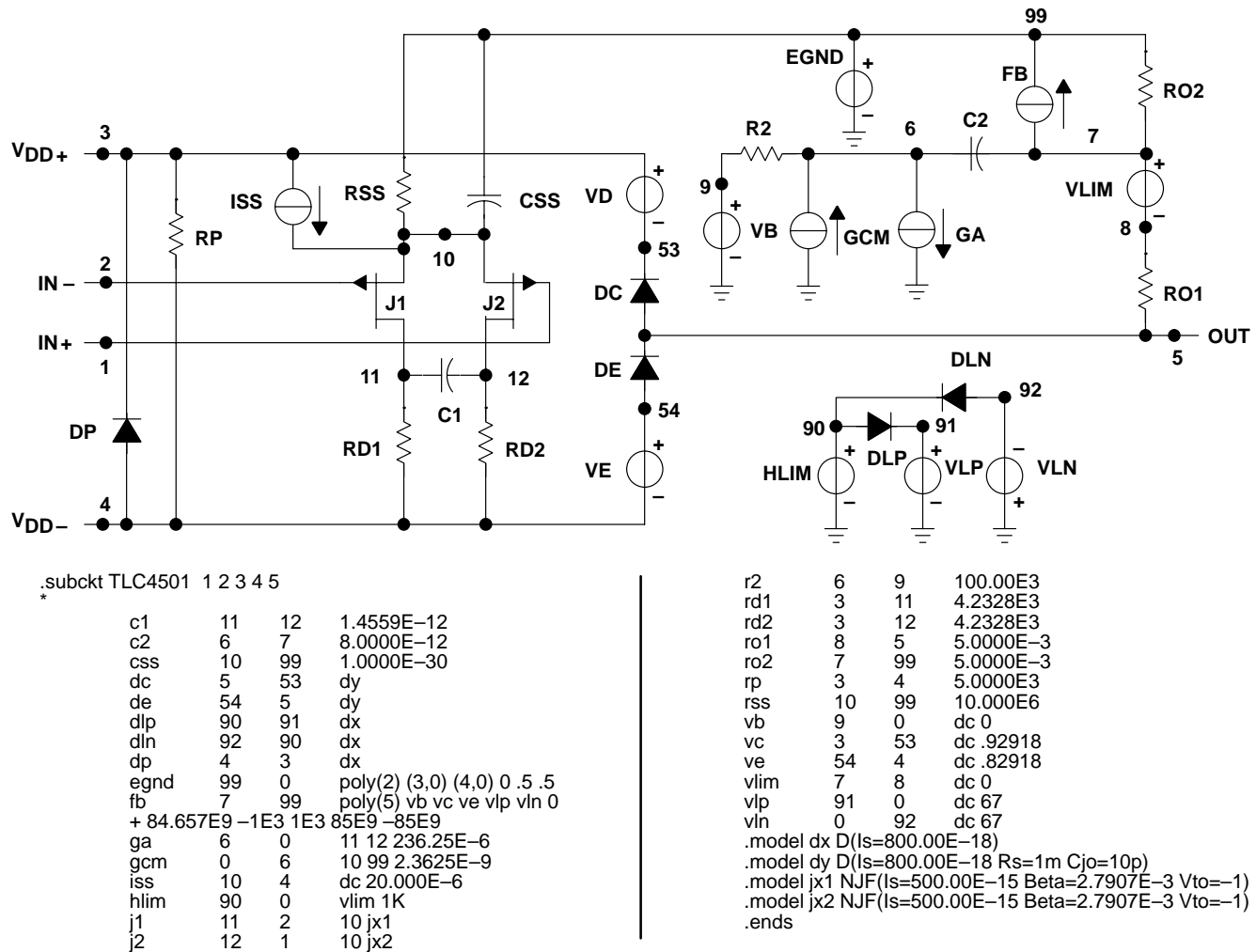
## APPLICATION INFORMATION

### macromodel information

Macromodel information provided was derived using Microsim *Parts*™ Release 8, the model generation software used with Microsim *PSpice*™. The Boyle macromodel (see Note 4) and subcircuit in Figure 46 are generated using the TLC4501 typical electrical and operating characteristics at  $T_A = 25^\circ\text{C}$ . Using this information, output simulations of the following key parameters can be generated to a tolerance of 20% (in most cases):

- Maximum positive output voltage swing
- Maximum negative output voltage swing
- Slew rate
- Quiescent power dissipation
- Input bias current
- Open-loop voltage amplification
- Unity-gain frequency
- Common-mode rejection ratio
- Phase margin
- DC output resistance
- AC output resistance
- Short-circuit output current limit

NOTE 4: G. R. Boyle, B. M. Cohn, D. O. Pederson, and J. E. Solomon, "Macromodeling of Integrated Circuit Operational Amplifiers", *IEEE Journal of Solid-State Circuits*, SC-9, 353 (1974).



**Figure 46. Boyle Macromodel and Subcircuit**

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**TLC4501, TLC4501A, TLC4502, TLC4502A**  
**FAMILY OF SELF-CALIBRATING (Self-Cal™)**  
**PRECISION CMOS RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS**

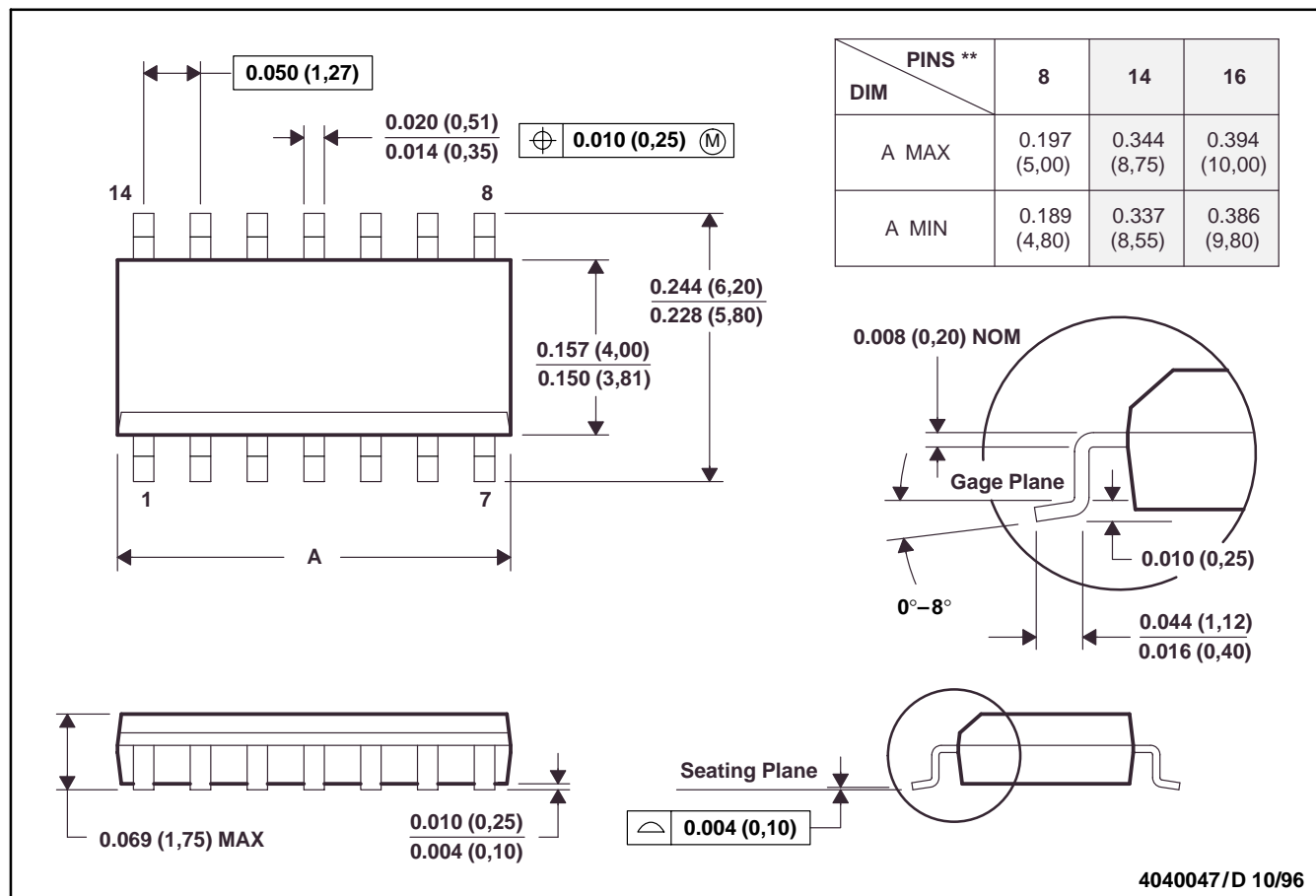
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**MECHANICAL INFORMATION**

**D (R-PDSO-G\*\*)**

**PLASTIC SMALL-OUTLINE PACKAGE**

14 PIN SHOWN



4040047/D 10/96

- 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

**TLC4501, TLC4501A, TLC4502, TLC4502A**  
**FAMILY OF SELF-CALIBRATING (Self-Cal™)**  
**PRECISION CMOS RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS**

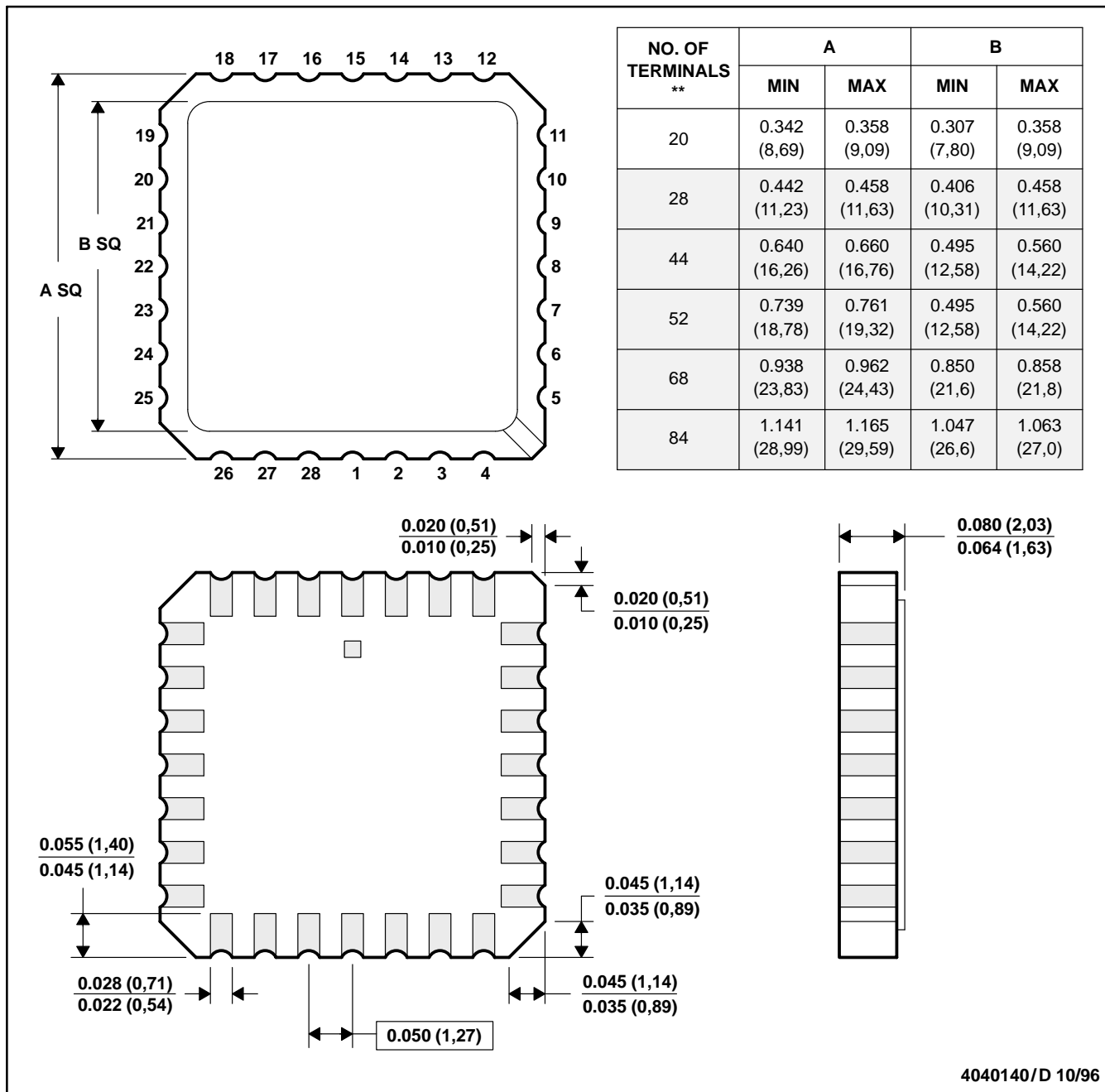
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**MECHANICAL INFORMATION**

**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

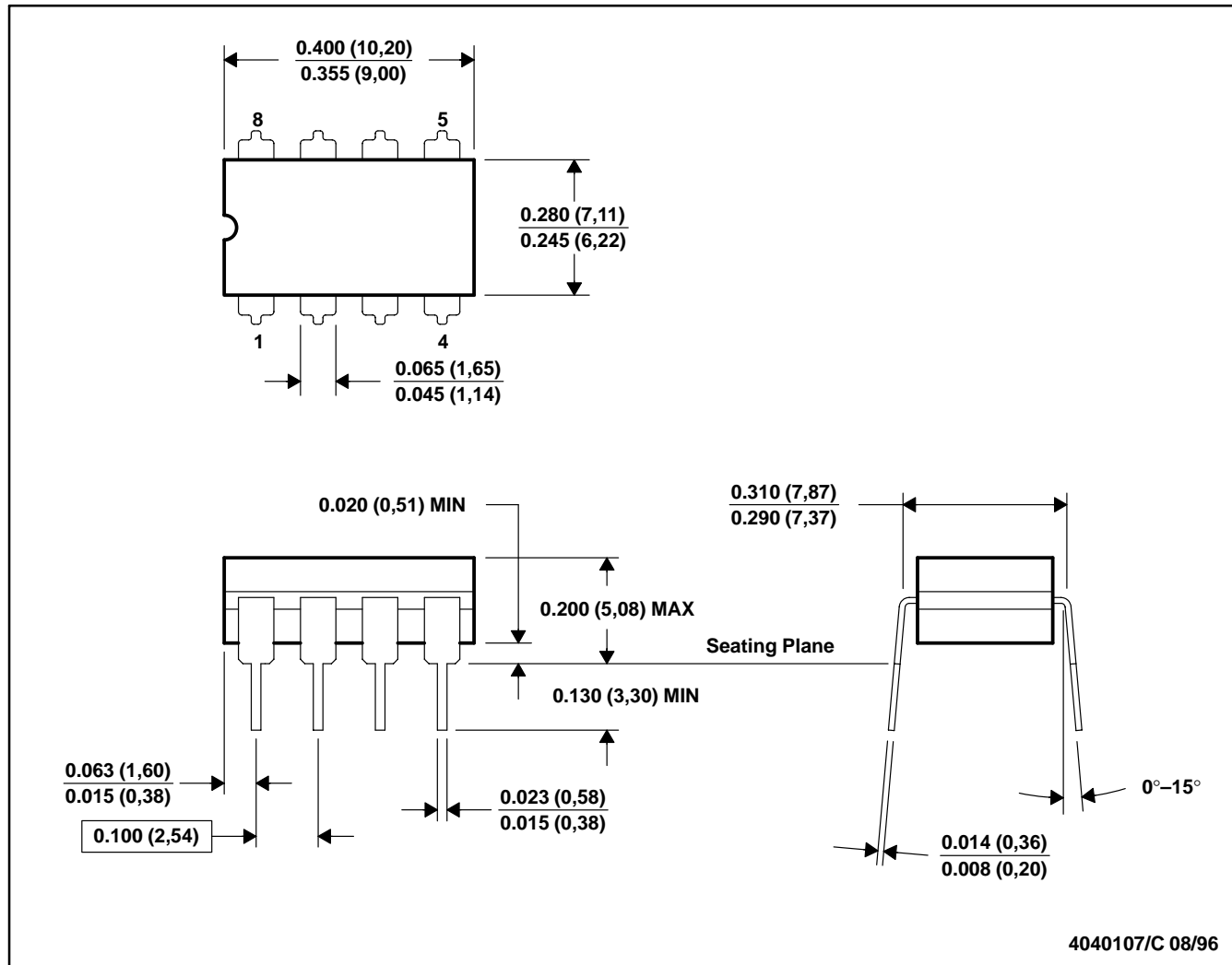
**TLC4501, TLC4501A, TLC4502, TLC4502A**  
**FAMILY OF SELF-CALIBRATING (Self-Cal™)**  
**PRECISION CMOS RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS**

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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 only.  
 E. Falls within MIL-STD-1835 GDIP1-T8



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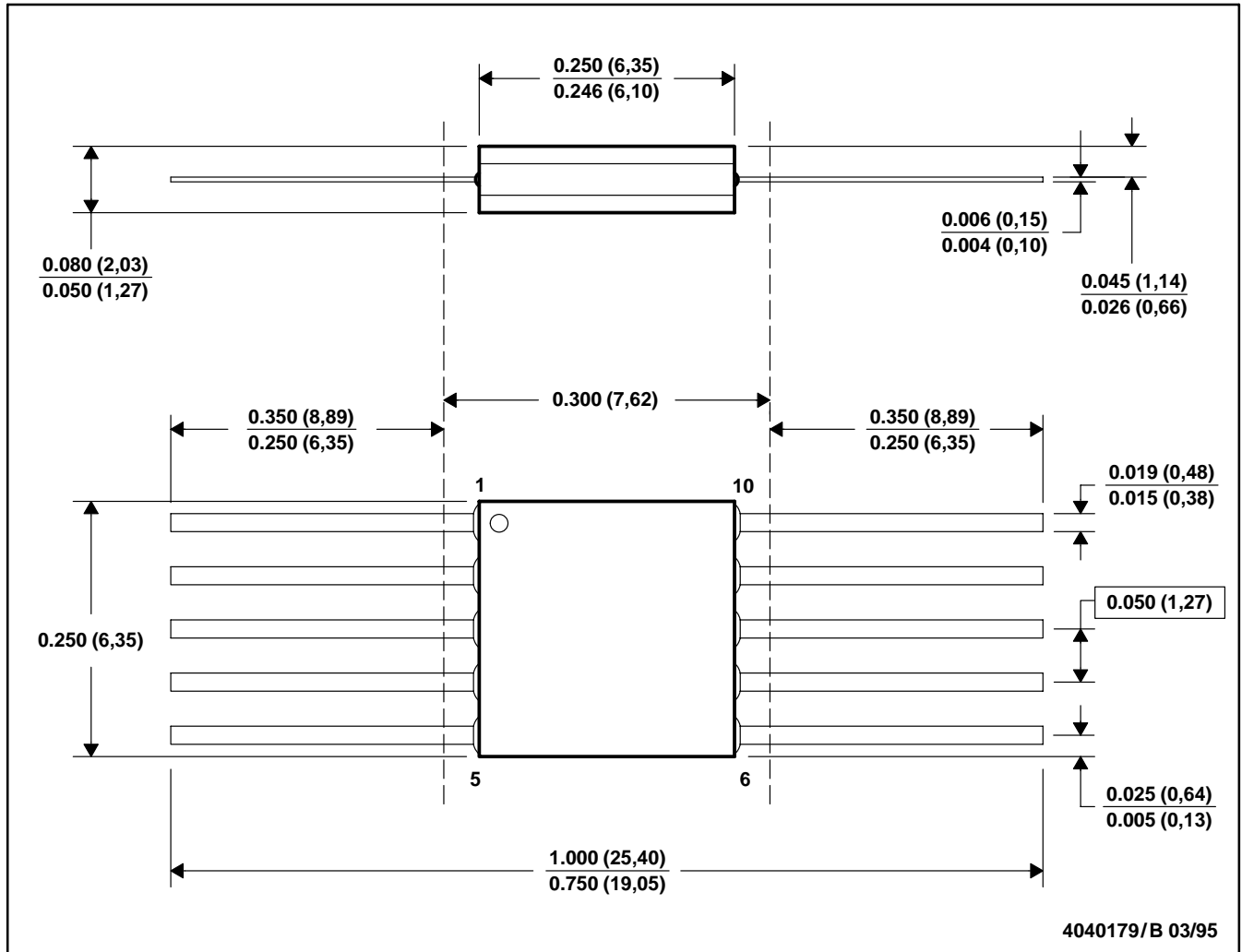
**TLC4501, TLC4501A, TLC4502, TLC4502A**  
**FAMILY OF SELF-CALIBRATING (Self-Cal™)**  
**PRECISION CMOS RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS**

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**MECHANICAL INFORMATION**

**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

**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
5962-9753701Q2A	ACTIVE	LCCC	FK	20	1	None	POST-PLATE	Level-NC-NC-NC
5962-9753701QHA	ACTIVE	CFP	U	10	1	None	A42 SNPB	Level-NC-NC-NC
5962-9753701QPA	ACTIVE	CDIP	JG	8	1	None	A42 SNPB	Level-NC-NC-NC
5962-9753702Q2A	ACTIVE	LCCC	FK	20	1	None	POST-PLATE	Level-NC-NC-NC
5962-9753702QHA	ACTIVE	CFP	U	10	1	None	A42 SNPB	Level-NC-NC-NC
5962-9753702QPA	ACTIVE	CDIP	JG	8	1	None	A42 SNPB	Level-NC-NC-NC
TLC4501ACD	ACTIVE	SOIC	D	8	75	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4501ACDR	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4501AID	ACTIVE	SOIC	D	8	75	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4501AIDR	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4501AQD	PREVIEW	SOIC	D	8		None	Call TI	Call TI
TLC4501AQDR	PREVIEW	SOIC	D	8		None	Call TI	Call TI
TLC4501CD	ACTIVE	SOIC	D	8	75	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4501CDR	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4501ID	ACTIVE	SOIC	D	8	75	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4501IDR	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4501QD	PREVIEW	SOIC	D	8		None	Call TI	Call TI
TLC4501QDR	PREVIEW	SOIC	D	8		None	Call TI	Call TI
TLC4502ACD	ACTIVE	SOIC	D	8	75	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4502ACDR	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4502AID	ACTIVE	SOIC	D	8	75	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4502AIDR	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4502AMD	ACTIVE	SOIC	D	8	75	None	CU NIPDAU	Level-1-220C-UNLIM
TLC4502AMFKB	ACTIVE	LCCC	FK	20	1	None	POST-PLATE	Level-NC-NC-NC
TLC4502AMJG	ACTIVE	CDIP	JG	8	1	None	A42 SNPB	Level-NC-NC-NC
TLC4502AMJGB	ACTIVE	CDIP	JG	8	1	None	A42 SNPB	Level-NC-NC-NC
TLC4502AMUB	ACTIVE	CFP	U	10	1	None	A42 SNPB	Level-NC-NC-NC
TLC4502AQD	ACTIVE	SOIC	D	8	75	None	CU NIPDAU	Level-1-220C-UNLIM
TLC4502AQDR	ACTIVE	SOIC	D	8	2500	None	CU NIPDAU	Level-1-220C-UNLIM
TLC4502CD	ACTIVE	SOIC	D	8	75	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4502CDR	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4502ID	ACTIVE	SOIC	D	8	75	Pb-Free	CU NIPDAU	Level-2-260C-1YEAR/



Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
						(RoHS)		Level-1-220C-UNLIM
TLC4502IDR	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-2-260C-1YEAR/ Level-1-220C-UNLIM
TLC4502MD	ACTIVE	SOIC	D	8	75	None	CU NIPDAU	Level-1-220C-UNLIM
TLC4502MFKB	ACTIVE	LCCC	FK	20	1	None	POST-PLATE	Level-NC-NC-NC
TLC4502MJG	ACTIVE	CDIP	JG	8	1	None	A42 SNPB	Level-NC-NC-NC
TLC4502MJGB	ACTIVE	CDIP	JG	8	1	None	A42 SNPB	Level-NC-NC-NC
TLC4502MUB	ACTIVE	CFP	U	10	1	None	A42 SNPB	Level-NC-NC-NC
TLC4502QD	ACTIVE	SOIC	D	8	75	None	CU NIPDAU	Level-1-220C-UNLIM
TLC4502QDR	ACTIVE	SOIC	D	8	2500	None	CU NIPDAU	Level-1-220C-UNLIM

<sup>(1)</sup> 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.

<sup>(2)</sup> Eco Plan - May not be currently available - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**None:** Not yet available Lead (Pb-Free).

**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.

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

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