- **Self-Calibrates Input Offset Voltage to 40 µV Max**
- **Low Input Offset Voltage Drift . . . 1 µV/°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/µs**
- **High Output Drive Capability . . . ±50 mA**
- **Calibration Time . . . 300 ms**
- **Characterized From –55°C to 125°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 µV typical and 40 µV maximum. This exceptional precision, combined with a 4.7-MHz bandwidth, 2.5-V/µs 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 µV 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.

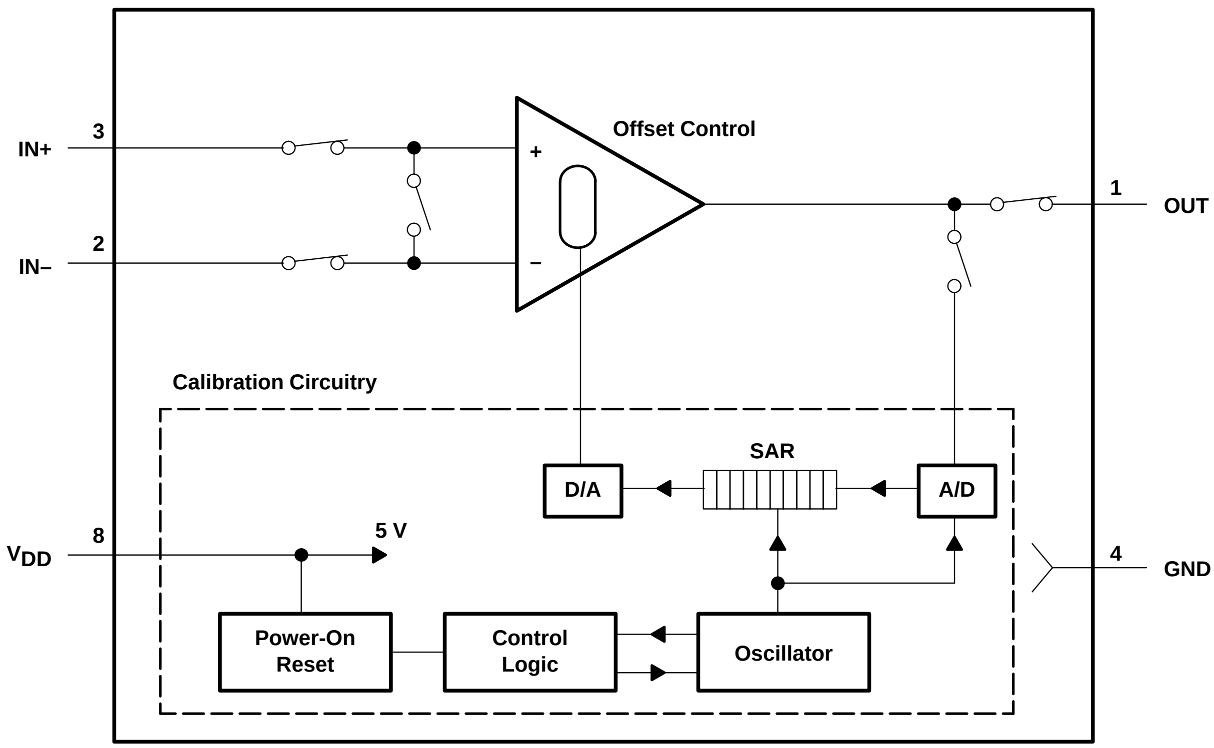

Figure 1. Channel One of the TLC4502

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.

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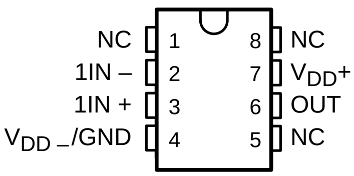
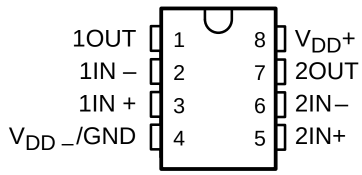
description (continued)

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

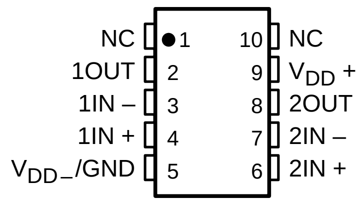
TLC4501
D PACKAGE
(TOP VIEW)



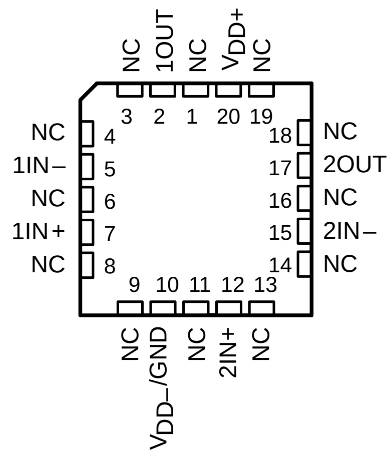
TLC4502
D OR JG PACKAGE
(TOP VIEW)



TLC4502
U PACKAGE
(TOP VIEW)



TLC4502
FK PACKAGE
(TOP VIEW)



NC – No internal connection

AVAILABLE OPTIONS

T_A	V_{IO}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.

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)	±7 V
Input voltage range, V_I (any input, see Note 1)	–0.3 V to 7 V
Input current, I_I (each input)	±5 mA
Output current, I_O (each output)	±100 mA
Total current into V_{DD+}	±100 mA
Total current out of V_{DD-}/GND	±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	$T_A \le 25°C$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25°C$	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING	$T_A = 125°C$ 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

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

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

operating characteristics, V_{DD} = 5 V

PARAMETER		TEST CONDITIONS		T_A†	TLC450xC, TLC450xAC MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	V_O = 0.5 V to 2.5 V,	C_L = 100 pF	25°C	1.5	2.5		V/µs
				Full range	1			V/µs
V_n	Equivalent input noise voltage	f = 10 Hz		25°C		70		nV/√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		µV
		f = 0.1 to 10 Hz		25°C		1.5		
I_n	Equivalent input noise current			25°C		0.6		fA/√Hz
THD + N	Total harmonic distortion plus noise	V_O = 0.5 V to 2.5 V, f = 10 kHz, R_L = 1 kΩ, C_L = 100 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 pF	R_L = 1 kΩ,	25°C		4.7		MHz
B_{OM}	Maximum output swing bandwidth	$V_{O(PP)}$ = 2 V, R_L = 1 kΩ,	A_V = 1, C_L = 100 pF	25°C		1		MHz
t_s	Settling time	A_V = –1, Step = 0.5 V to 2.5 V, R_L = 1 kΩ, C_L = 100 pF	to 0.1%	25°C		1.6		µs
			to 0.01%	25°C		2.2		
ϕ_m	Phase margin at unity gain	R_L = 1 kΩ,	C_L = 100 pF	25°C		74		
	Calibration time			25°C		300		ms

† Full range is 0°C to 70°C.

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

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

PARAMETER		TEST CONDITIONS		T_A†	TLC450xI MIN	TLC450xI TYP	TLC450xI MAX	UNIT
V_{IO}	Input offset voltage	V_{DD} = ±2.5 V, V_O = 0, V_{IC} = 0, R_S = 50 Ω	TLC4501	Full range	–80	10	80	µV
			TLC4501A		–40	10	40	
			TLC4502		–100	10	100	
			TLC4502A		–50	10	50	
α_{VIO}	Temperature coefficient of input offset voltage	V_{DD} = ±2.5 V, V_O = 0, V_{IC} = 0, R_S = 50 Ω		Full range		1		µV/°C
I_{IO}	Input offset current			25°C		1	60	pA
				–40°C to 85°C			500	
				Full range			5	nA
I_{IB}	Input bias current	V_{DD} = ±2.5 V, V_O = 0, V_{IC} = 0, R_S = 50 Ω		25°C		1	60	pA
				–40°C to 85°C			500	
				Full range			10	nA
V_{OH}	High-level output voltage	I_{OH} = – 500 µA		25°C		4.99		V
		I_{OH} = – 5 mA		25°C		4.9		
				Full range	4.7			
V_{OL}	Low-level output voltage	V_{IC} = 2.5 V, I_{OL} = 500 µA		25°C		0.01		V
		V_{IC} = 2.5 V, I_{OL} = 5 mA		25°C		0.1		
				Full range			0.3	
A_{VD}	Large-signal differential voltage amplification	V_{IC} = 2.5 V, V_O = 1 V to 4 V, R_L = 1 kΩ, See Note 4		25°C	200	1000		V/mV
				Full range	200			
$R_{I(D)}$	Differential input resistance			25°C		10		kΩ
R_L	Input resistance	See Note 4		25°C		10^{12}		Ω
C_L	Common-mode input capacitance	f = 10 kHz, P package		25°C		8		pF
z_O	Closed-loop output impedance	A_V = 10, f = 100 kHz		25°C		1		Ω
CMRR	Common-mode rejection ratio	V_{IC} = 0 to 2.7 V, V_O = 2.5 V, R_S = 1 kΩ		25°C	90	100		dB
				Full range	85			
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD\pm}/\Delta V_{IO}$)	V_{DD} = 4 V to 6 V, V_{IC} = 0, No load		25°C	90	100		dB
				Full range	90			
I_{DD}	Supply current	V_O = 2.5 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 –40°C to 125°C.
NOTE 4: R_L and C_L values are referenced to 2.5 V.

operating characteristics, V_{DD} = 5 V

PARAMETER		TEST CONDITIONS		T_A†	TLC450xI, TLC450xAI MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	V_O = 0.5 V to 2.5 V,	C_L = 100 pF	25°C	1.5	2.5		V/μs
				Full range	1			V/μs
V_n	Equivalent input noise voltage	f = 10 Hz		25°C		70		nV/√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		μV
		f = 0.1 to 10 Hz		25°C		1.5		
I_n	Equivalent input noise current			25°C		0.6		fA/√Hz
THD + N	Total harmonic distortion plus noise	V_O = 0.5 V to 2.5 V, f = 10 kHz, R_L = 1 kΩ, C_L = 100 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 pF	R_L = 1 kΩ,	25°C		4.7		MHz
B_{OM}	Maximum output swing bandwidth	$V_{O(PP)}$ = 2 V, R_L = 1 kΩ,	A_V = 1, C_L = 100 pF	25°C		1		MHz
t_s	Settling time	A_V = –1, Step = 0.5 V to 2.5 V, R_L = 1 kΩ, C_L = 100 pF	to 0.1%	25°C		1.6		μs
			to 0.01%	25°C		2.2		
ϕ_m	Phase margin at unity gain	R_L = 1 kΩ,	C_L = 100 pF	25°C		74		
	Calibration time			25°C		300		ms

† Full range is –40°C to 125°C.
NOTE 4: R_L and C_L values are referenced to 2.5 V.

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

PARAMETER		TEST CONDITIONS		T_A†	TLC4502Q, TLC4502M MIN	TYP	MAX	UNIT
V_{IO}	Input offset voltage	V_{DD} = ±2.5 V, V_O = 0, V_{IC} = 0, R_S = 50 Ω	TLC4502	Full range	–100	10	100	µV
			TLC4502A		–50	10	50	
α_{VIO}	Temperature coefficient of input offset voltage	V_{DD} = ±2.5 V, V_O = 0, V_{IC} = 0, R_S = 50 Ω		Full range		1		µV/°C
I_{IO}	Input offset current			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 µA		25°C		4.99		V
		I_{OH} = – 5 mA		25°C		4.9		
				Full range	4.7			
V_{OL}	Low-level output voltage	V_{IC} = 2.5 V, I_{OL} = 500 µA		25°C		0.01		V
		V_{IC} = 2.5 V, I_{OL} = 5 mA		25°C		0.1		
				Full range			0.3	
A_{VD}	Large-signal differential voltage amplification	V_{IC} = 2.5 V, V_O = 1 V to 4 V, R_L = 1 kΩ, See Note 4		25°C	200	1000		V/mV
				Full range	200			
$R_{I(D)}$	Differential input resistance			25°C		10		kΩ
R_L	Input resistance	See Note 4		25°C		10^{12}		Ω
C_L	Common-mode input capacitance	f = 10 kHz, P package		25°C		8		pF
z_O	Closed-loop output impedance	A_V = 10, f = 100 kHz		25°C		1		Ω
CMRR	Common-mode rejection ratio	V_{IC} = 0 to 2.7 V, V_O = 2.5 V, R_S = 1 kΩ		25°C	90	100		dB
				Full range	85			
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD\pm}/\Delta V_{IO}$)	V_{DD} = 4 V to 6 V, V_{IC} = V_{DD} /2, No load		25°C	90	100		dB
				Full range	90			
I_{DD}	Supply current	V_O = 2.5 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°C to 125°C for Q suffix, –55°C to 125°C for M suffix.
NOTE 4: R_L and C_L values are referenced to 2.5 V.

operating characteristics, V_{DD} = 5 V

PARAMETER		TEST CONDITIONS		T_A†	TLC4502Q, TLC4502M, TLC4502AQ, TLC4502AM MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	V_O = 0.5 V to 2.5 V, See Note 4	C_L = 100 pF	25°C	1.5	2.5		V/µs
				Full range	1			V/µs
V_n	Equivalent input noise voltage	f = 10 Hz		25°C		70		nV/√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		µV
		f = 0.1 to 10 Hz		25°C		1.5		
I_n	Equivalent input noise current			25°C		0.6		fA/√Hz
THD + N	Total harmonic distortion plus noise	V_O = 0.5 V to 2.5 V, f = 10 kHz, R_L = 1 kΩ, C_L = 100 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 pF	R_L = 1 kΩ,	25°C		4.7		MHz
B_{OM}	Maximum output swing bandwidth	$V_{O(PP)}$ = 2 V, R_L = 1 kΩ,	A_V = 1, C_L = 100 pF	25°C		1		MHz
t_s	Settling time	A_V = –1, Step = 0.5 V to 2.5 V, R_L = 1 kΩ, C_L = 100 pF	to 0.1%	25°C		1.6		µs
			to 0.01%	25°C		2.2		
ϕ_m	Phase margin at unity gain	R_L = 1 kΩ,	C_L = 100 pF	25°C		74		
	Calibration time			25°C		300		ms

† Full range is –40°C to 125°C for Q suffix, –55°C to 125°C for M suffix.
NOTE 4: R_L and C_L values are referenced to 2.5 V.

TYPICAL CHARACTERISTICS

Table of Graphs

			FIGURE
V_{IO}	Input offset voltage	Distribution	2, 3, 4
		vs Common-mode input voltage	5
α_{VIO}	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 vs Frequency	13 14
z_o	Output impedance	vs Frequency	15
CMRR	Common-mode rejection ratio	vs Frequency vs Free-air temperature	16 17
SR	Slew rate	vs Load capacitance vs Free-air temperature	18 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
	Input noise voltage	Over a 10-second period	25
THD + N	Total harmonic distortion plus noise	vs Frequency	26
	Gain-bandwidth product	vs Free-air temperature	27
ϕ_m	Phase margin	vs Load capacitance	28
		vs Frequency	14
	Gain margin	vs Load capacitance	29
PSRR	Power-supply rejection ratio	vs Free-air temperature	30
	Calibration time at –40°C		31
	Calibration time at 25°C		32
	Calibration time at 85°C		33
	Calibration time at 125°C		34

TYPICAL CHARACTERISTICS

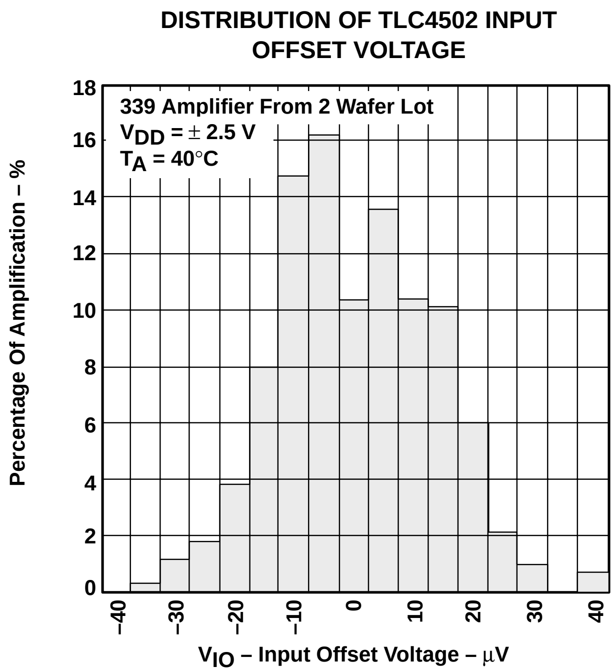


Figure 2

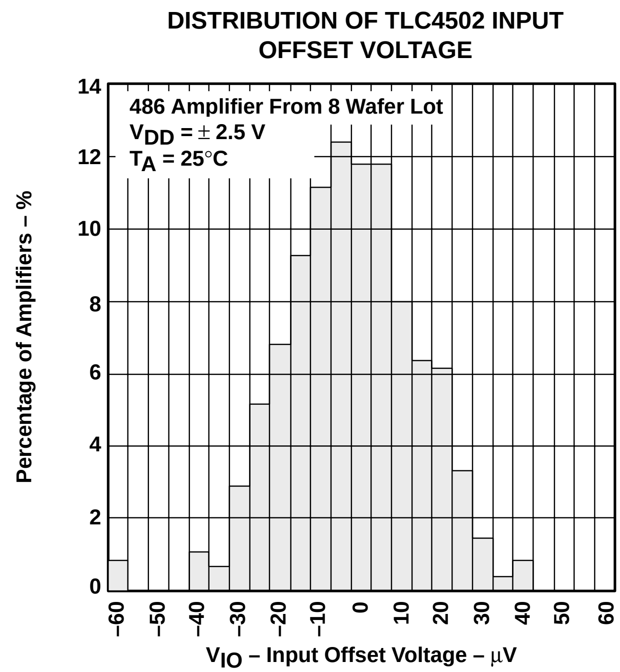


Figure 3

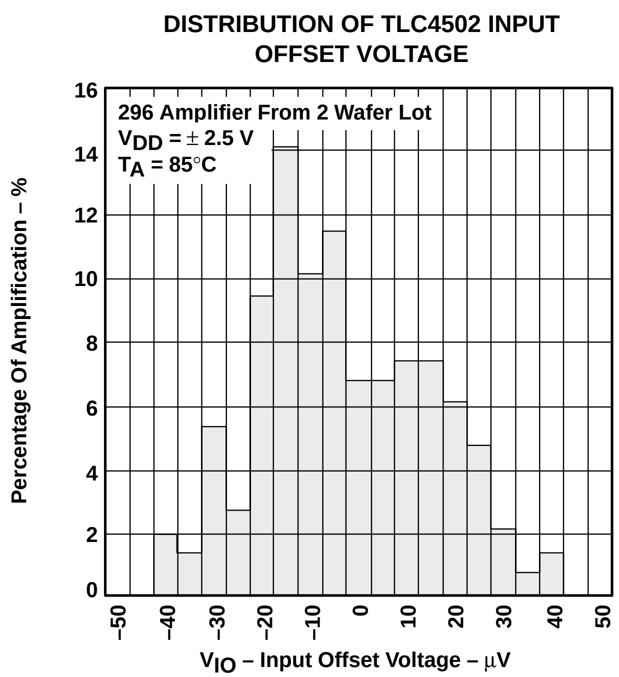


Figure 4

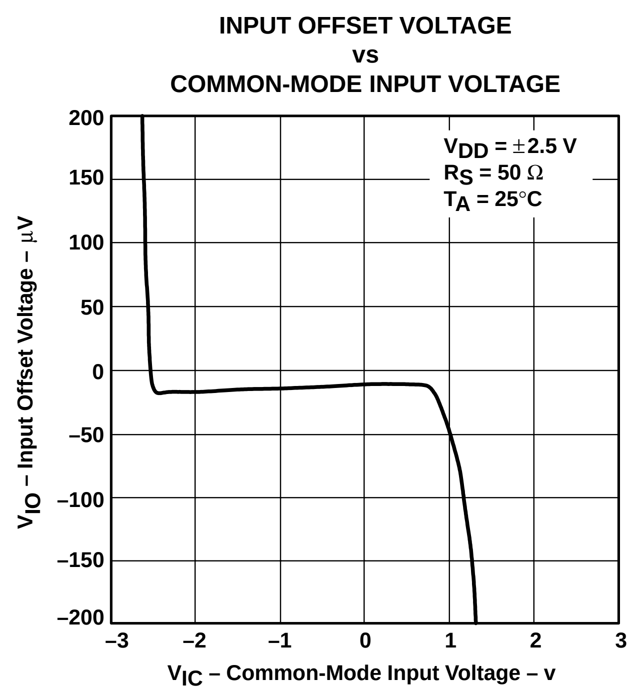


Figure 5

TYPICAL CHARACTERISTICS

DISTRIBUTION OF TLC4502 INPUT OFFSET VOLTAGE TEMPERATURE COEFFICIENT

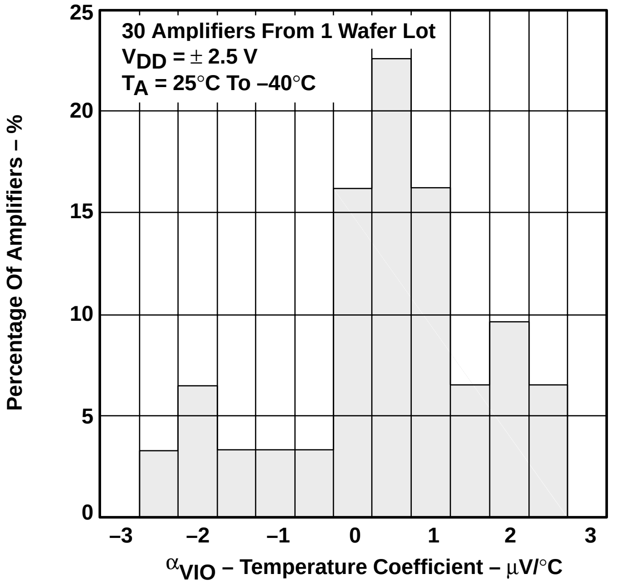


Figure 6

DISTRIBUTION OF TLC4502 INPUT OFFSET VOLTAGE TEMPERATURE COEFFICIENT

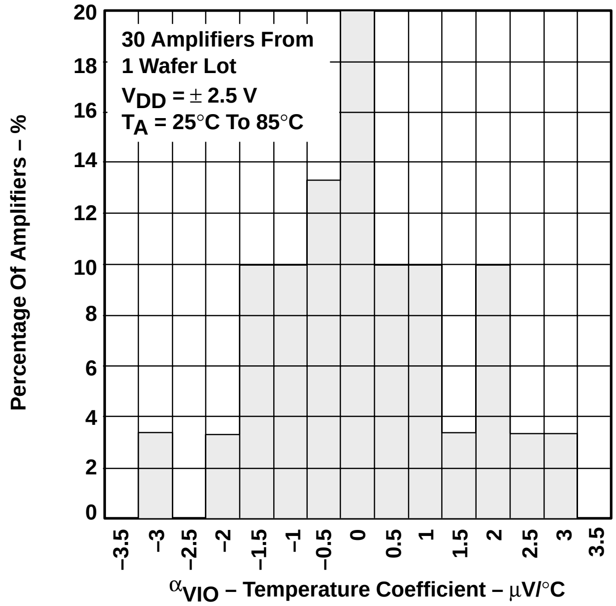


Figure 7

HIGH-LEVEL OUTPUT VOLTAGE vs HIGH-LEVEL OUTPUT CURRENT

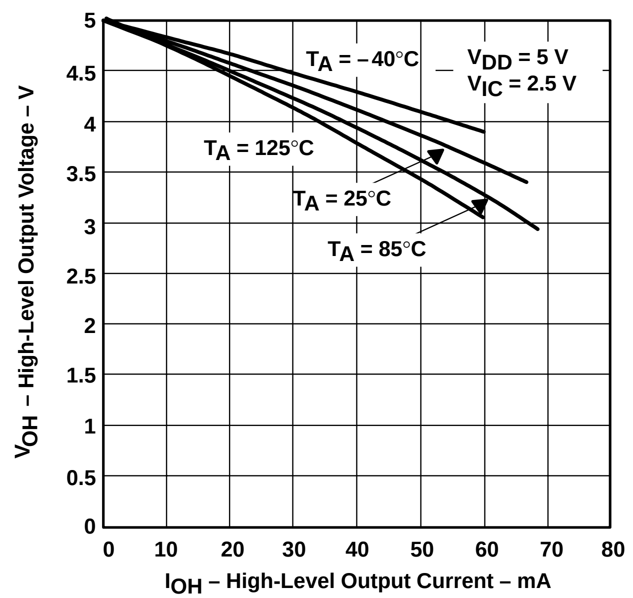


Figure 8

LOW-LEVEL OUTPUT VOLTAGE vs LOW-LEVEL OUTPUT CURRENT

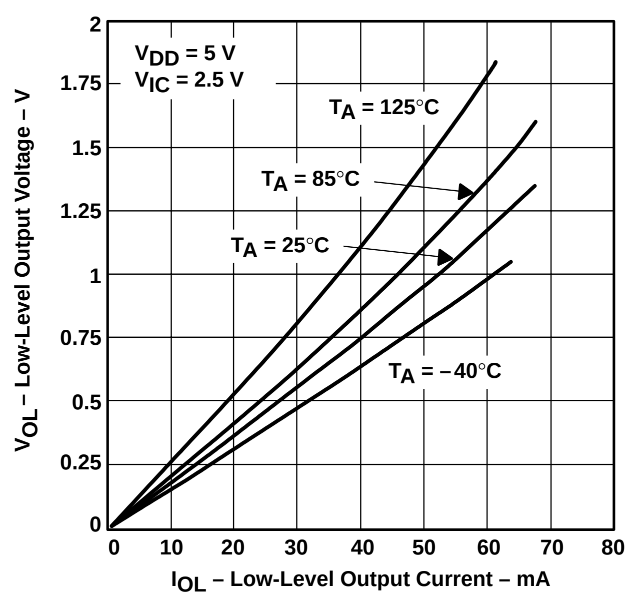


Figure 9

TYPICAL CHARACTERISTICS

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE vs FREQUENCY

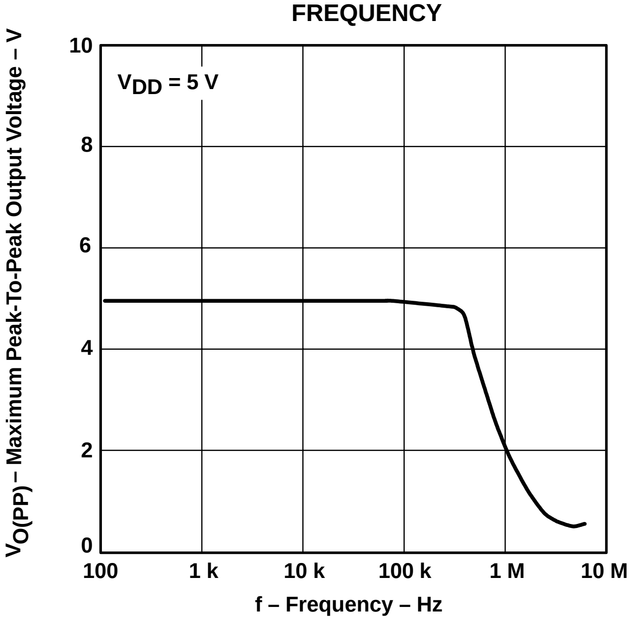


Figure 10

SHORT-CIRCUIT OUTPUT CURRENT vs FREE-AIR TEMPERATURE

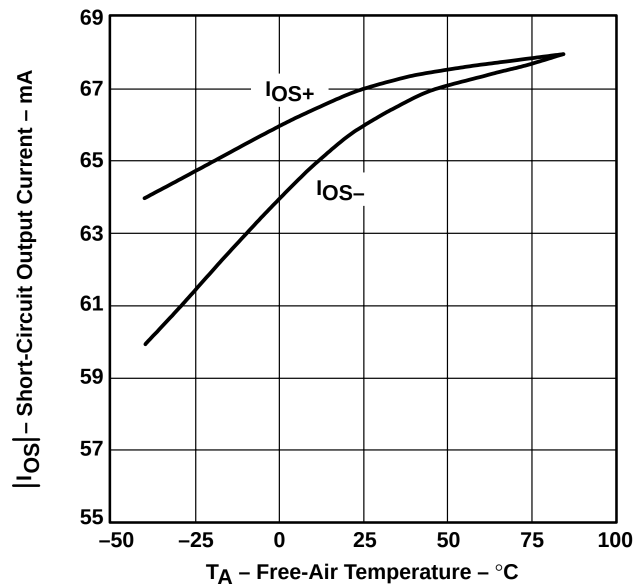


Figure 11

OUTPUT VOLTAGE vs DIFFERENTIAL INPUT VOLTAGE

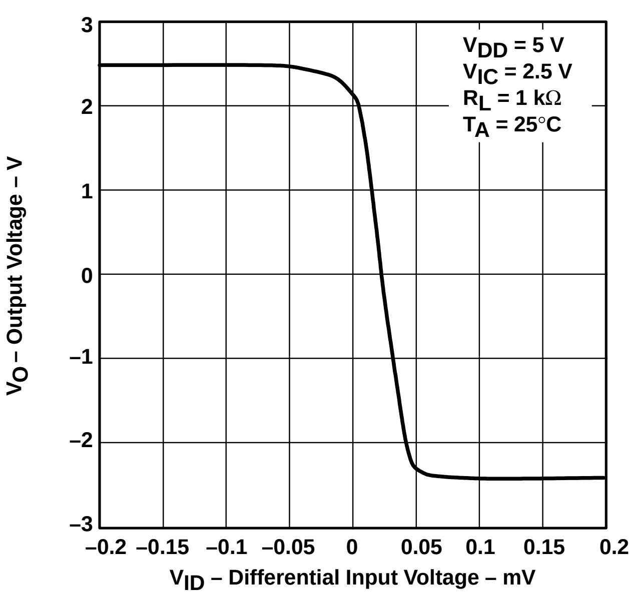


Figure 12

LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION vs FREE-AIR TEMPERATURE

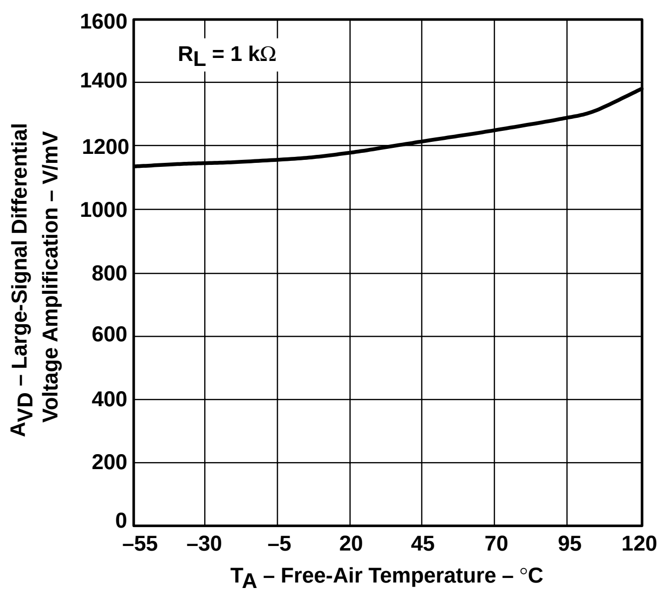


Figure 13

TYPICAL CHARACTERISTICS

LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION AND PHASE MARGIN vs FREQUENCY

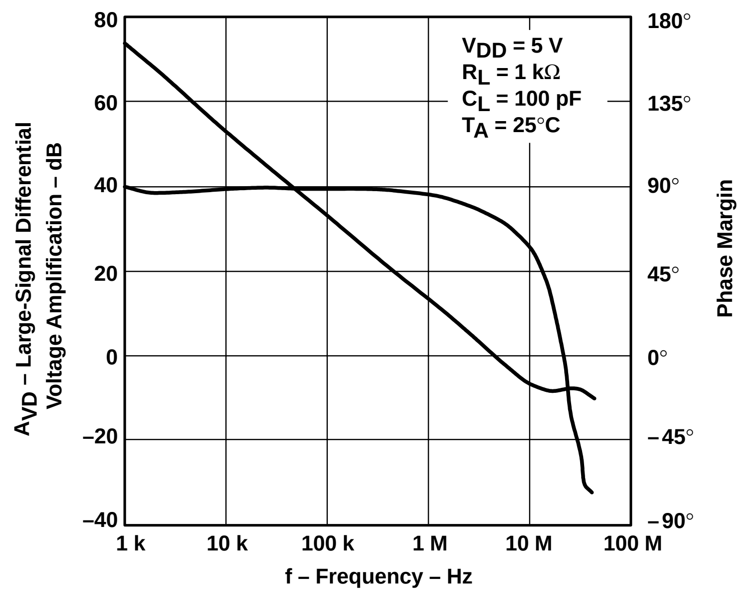


Figure 14

OUTPUT IMPEDANCE vs FREQUENCY

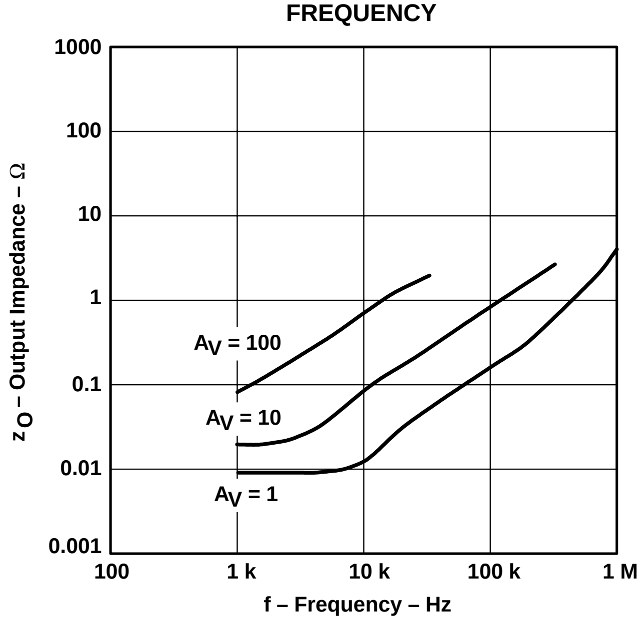


Figure 15

TYPICAL CHARACTERISTICS

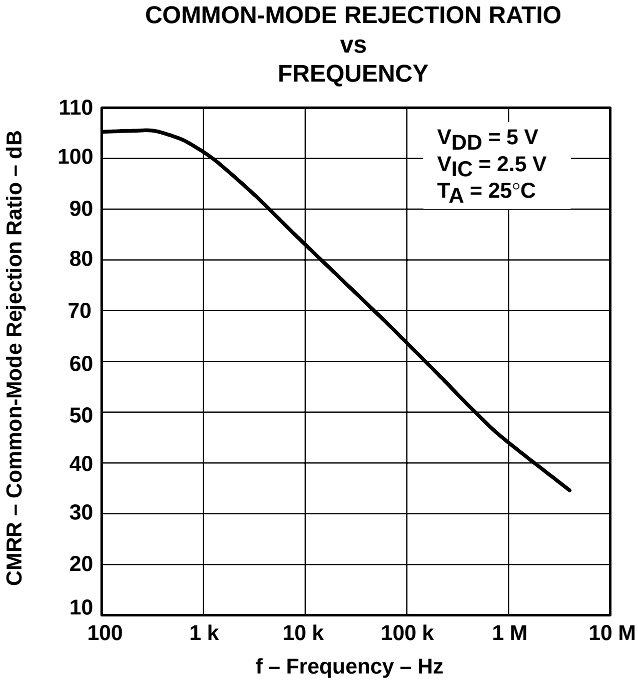


Figure 16

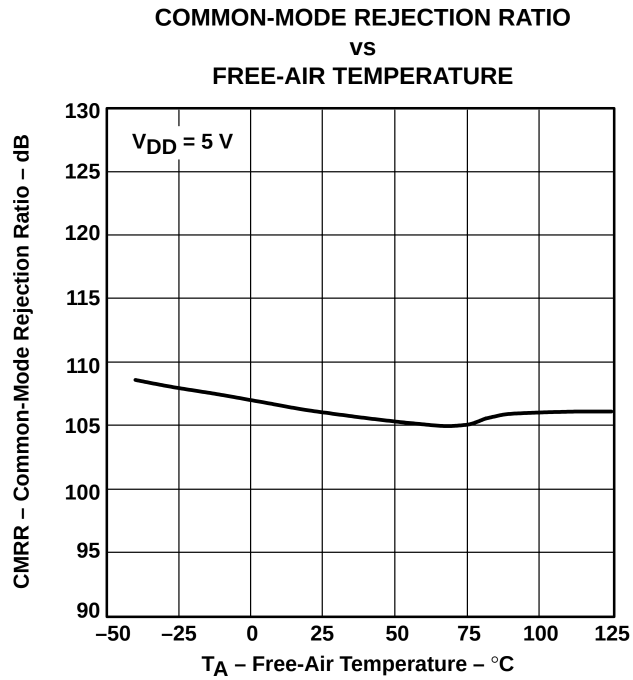


Figure 17

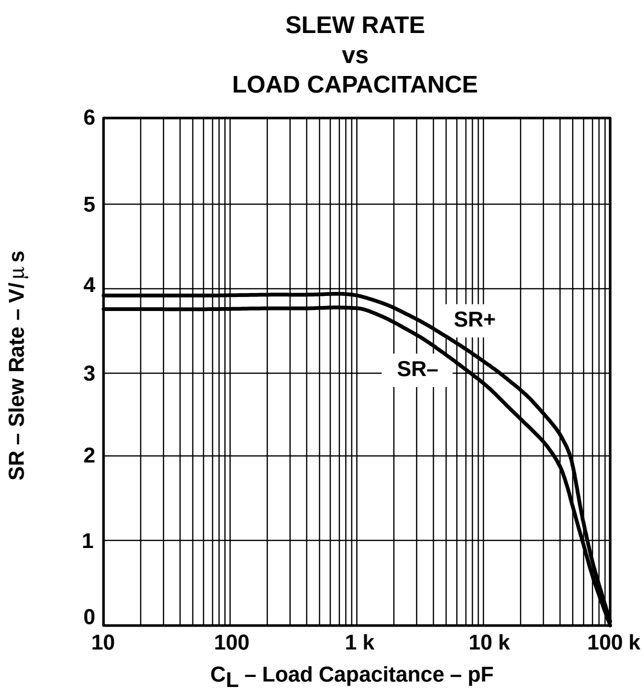


Figure 18

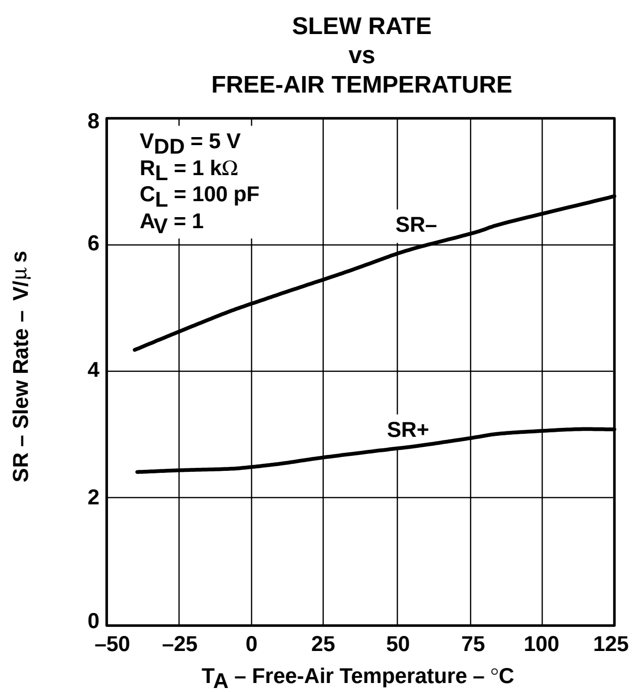


Figure 19

TYPICAL CHARACTERISTICS

INVERTING LARGE-SIGNAL PULSE RESPONSE

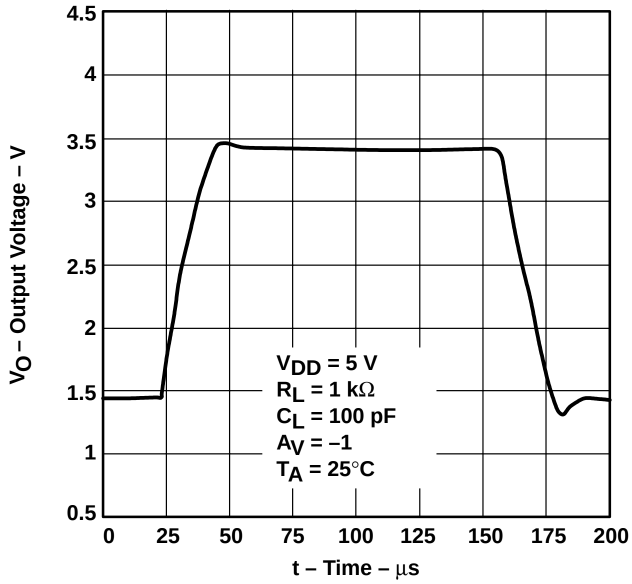


Figure 20

VOLTAGE-FOLLOWER LARGE-SIGNAL PULSE RESPONSE

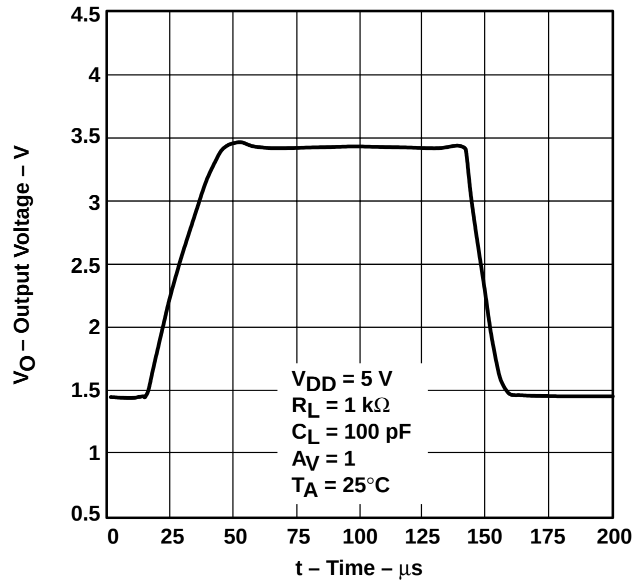


Figure 21

INVERTING SMALL-SIGNAL PULSE RESPONSE

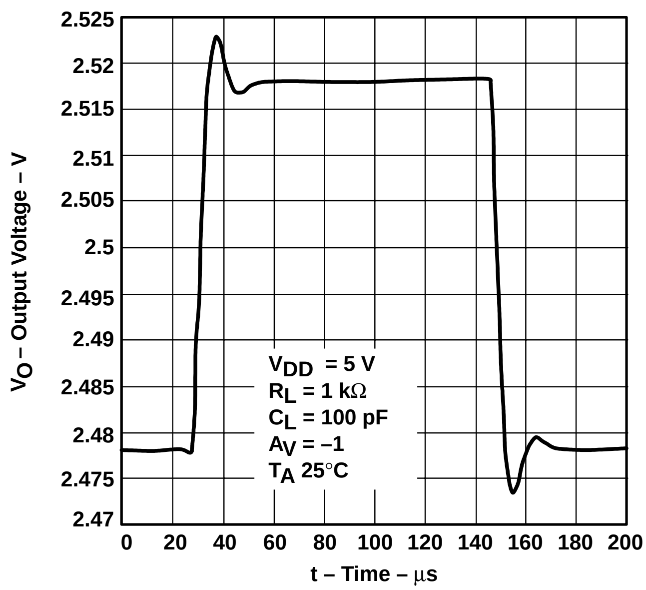


Figure 22

VOLTAGE-FOLLOWER SMALL-SIGNAL PULSE RESPONSE

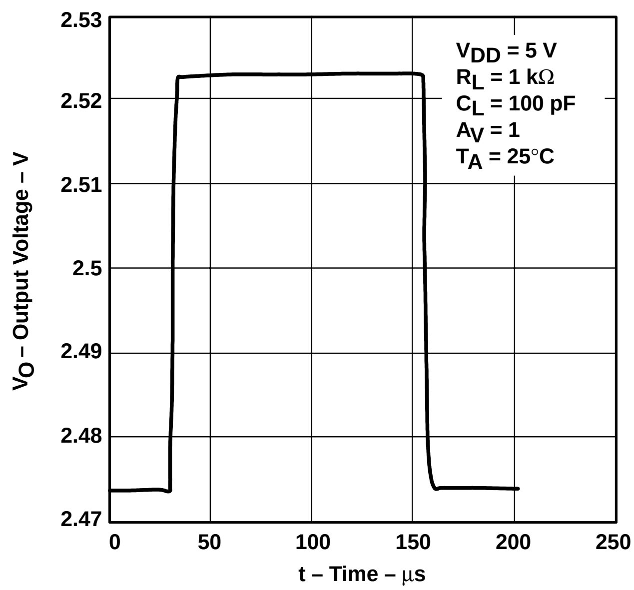


Figure 23

TYPICAL CHARACTERISTICS

EQUIVALENT INPUT NOISE VOLTAGE vs FREQUENCY

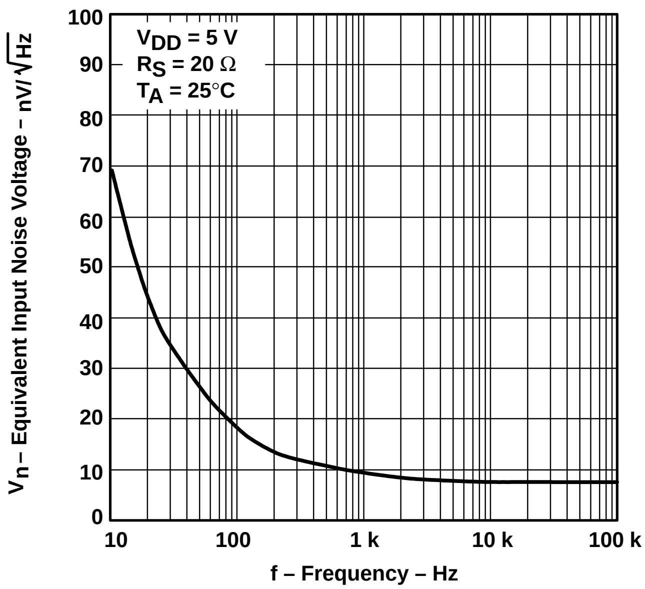


Figure 24

INPUT NOISE VOLTAGE OVER A 10-SECOND PERIOD

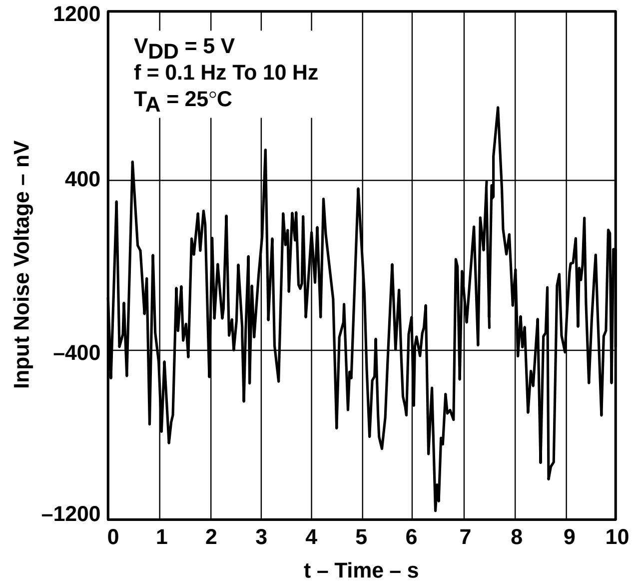


Figure 25

TOTAL HARMONIC DISTORTION PLUS NOISE vs FREQUENCY

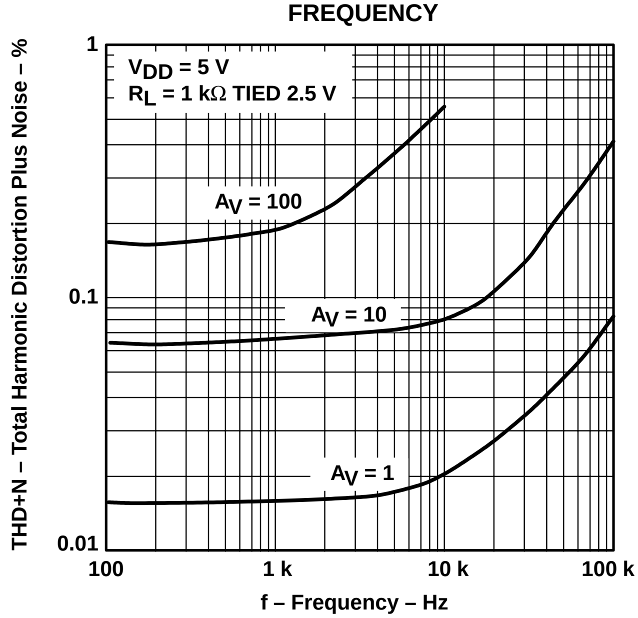


Figure 26

GAIN-BANDWIDTH PRODUCT vs FREE-AIR TEMPERATURE

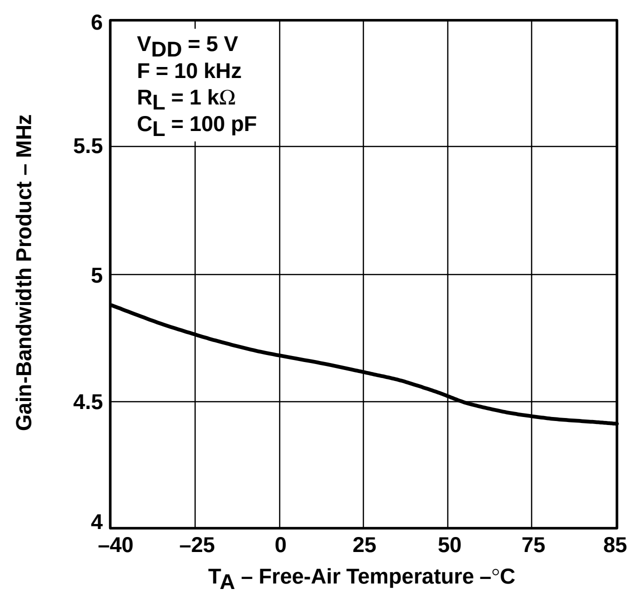


Figure 27

TYPICAL CHARACTERISTICS

PHASE MARGIN
vs
LOAD CAPACITANCE

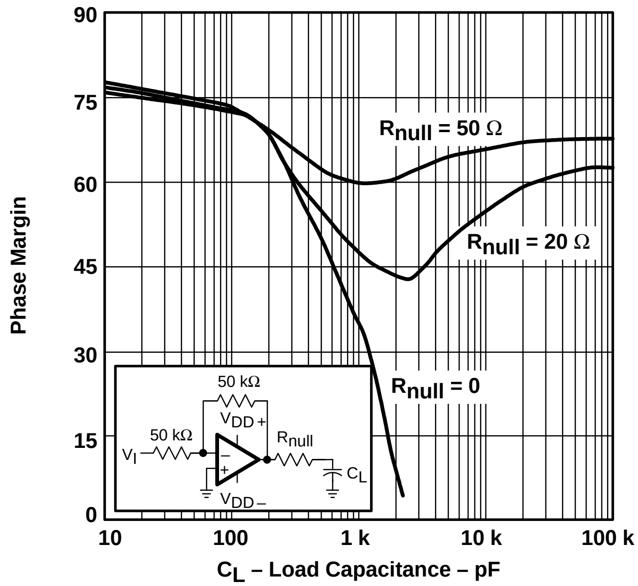


Figure 28

GAIN MARGIN
vs
LOAD CAPACITANCE

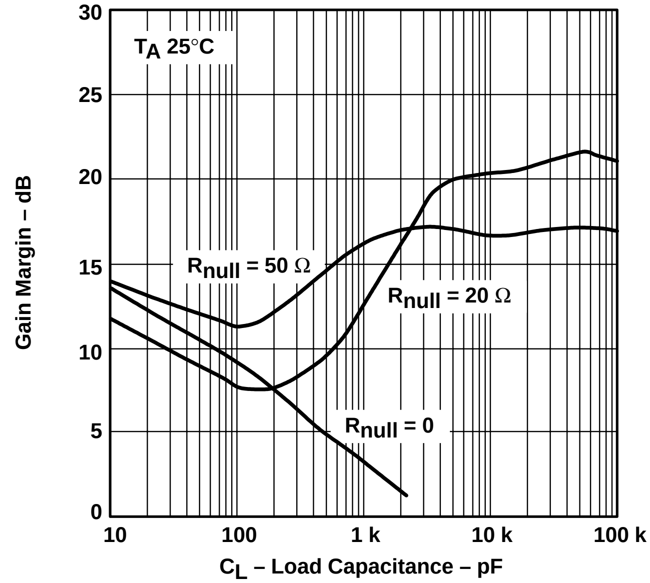


Figure 29

POWER SUPPLY REJECTION RATIO
vs
FREE-AIR TEMPERATURE

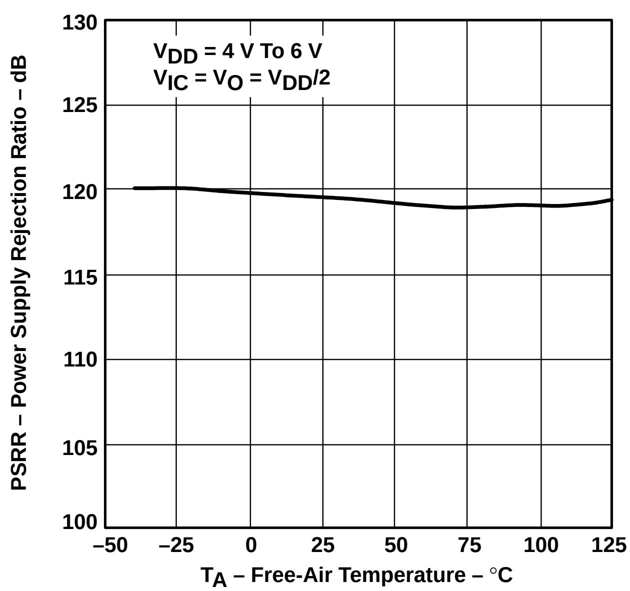


Figure 30

CALIBRATION TIME AT –40°C

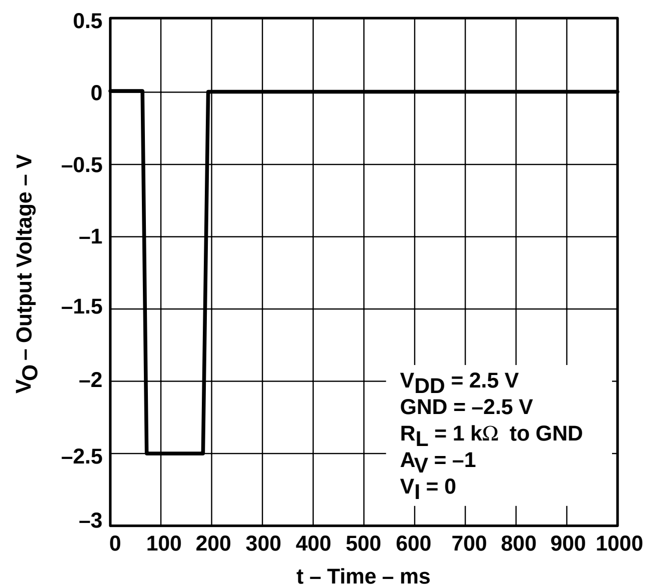


Figure 31

TYPICAL CHARACTERISTICS

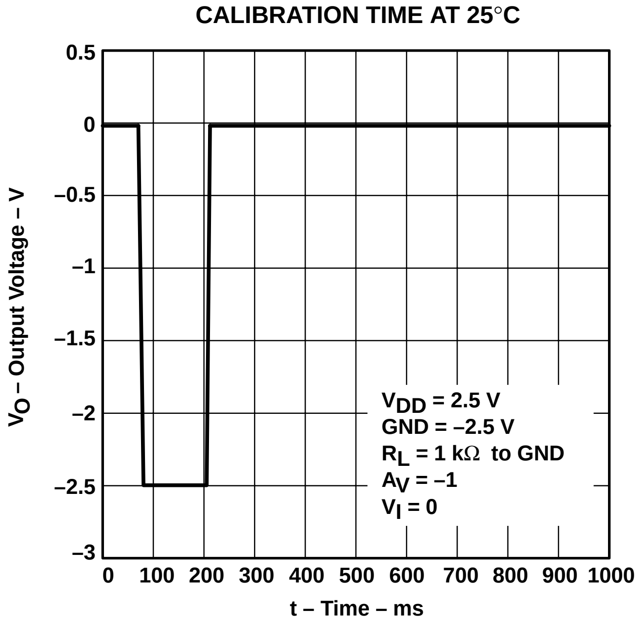


Figure 32

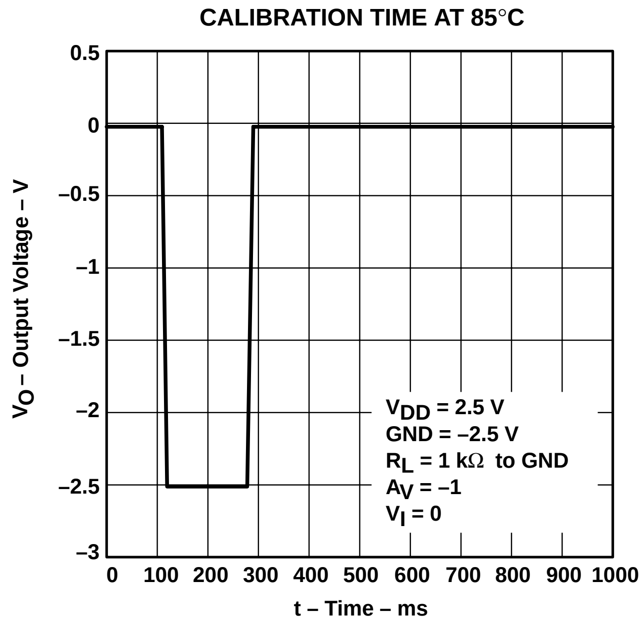


Figure 33

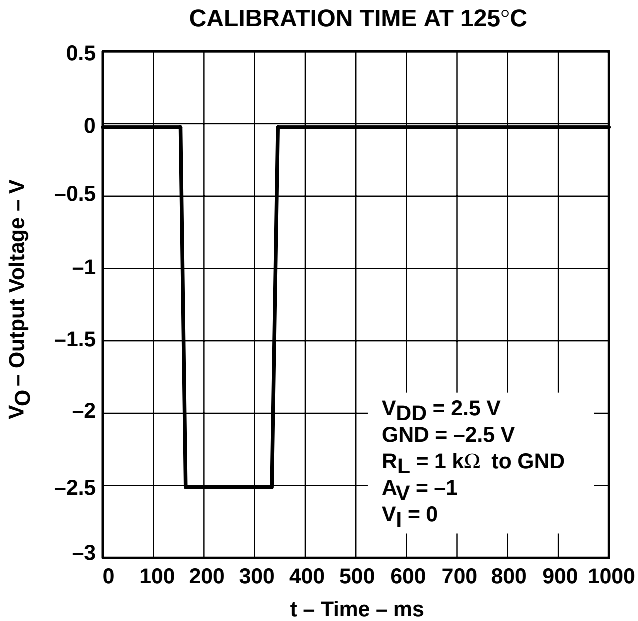


Figure 34

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 V at 25°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 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.

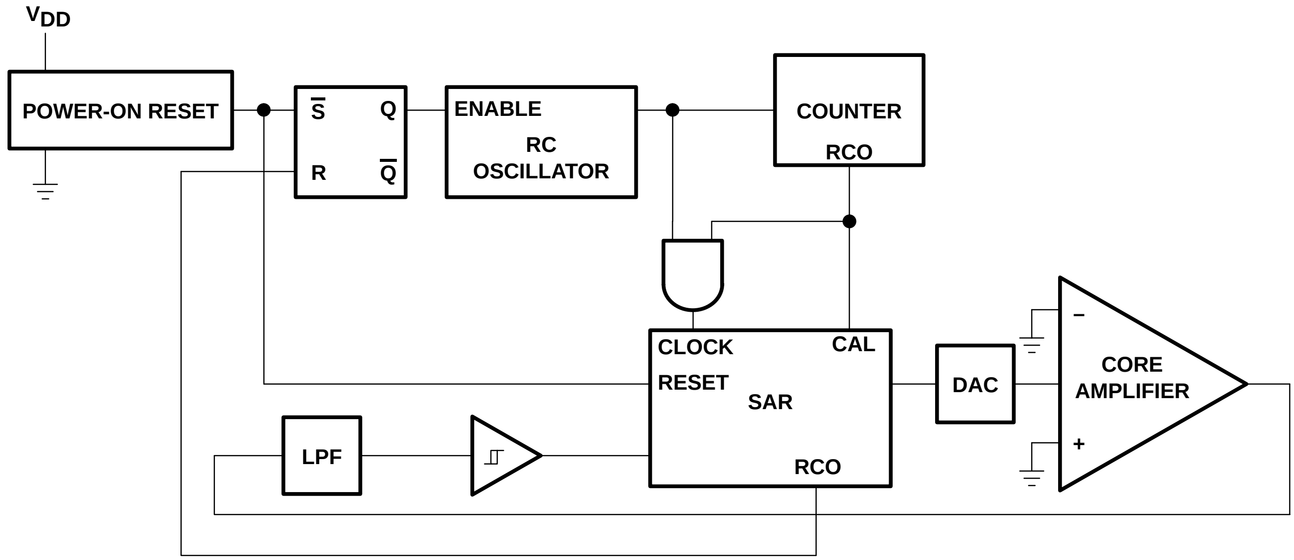


Figure 35. Block Diagram During Calibration Mode

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 µs, 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 µs 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 ±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.

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:

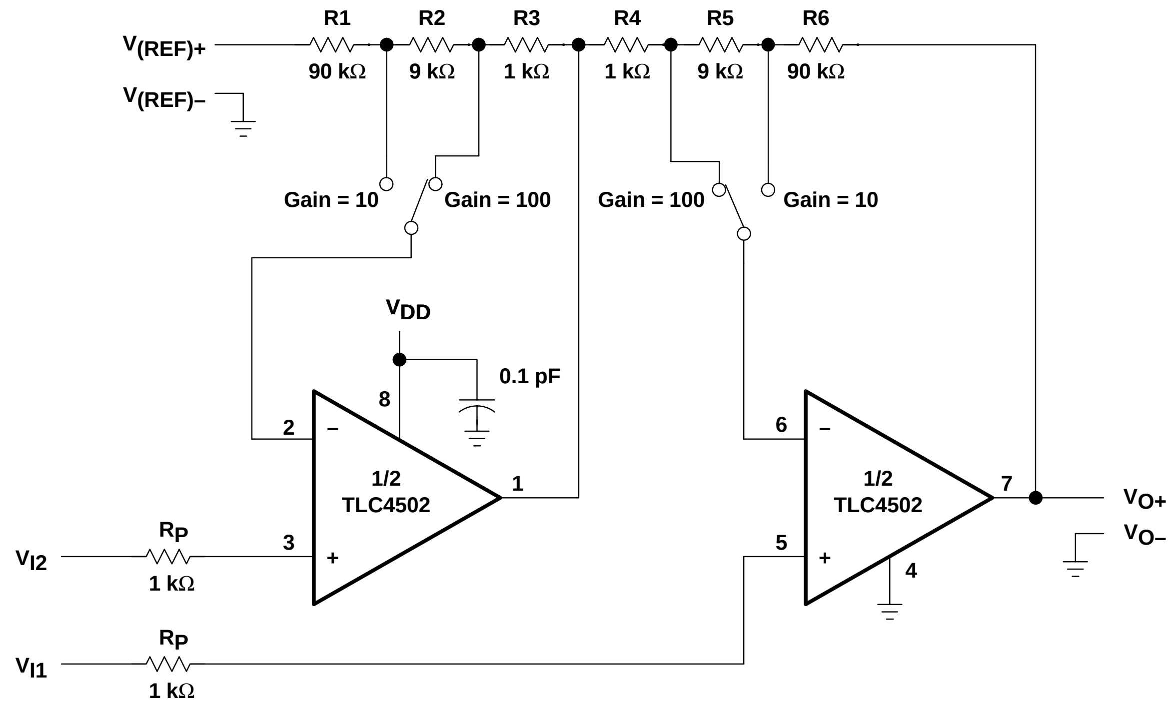
- Data acquisition systems
- Medical equipment
- Portable digital scales
- Strain gauges
- Automotive sensors
- Digital audio circuits
- Industrial control applications

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.

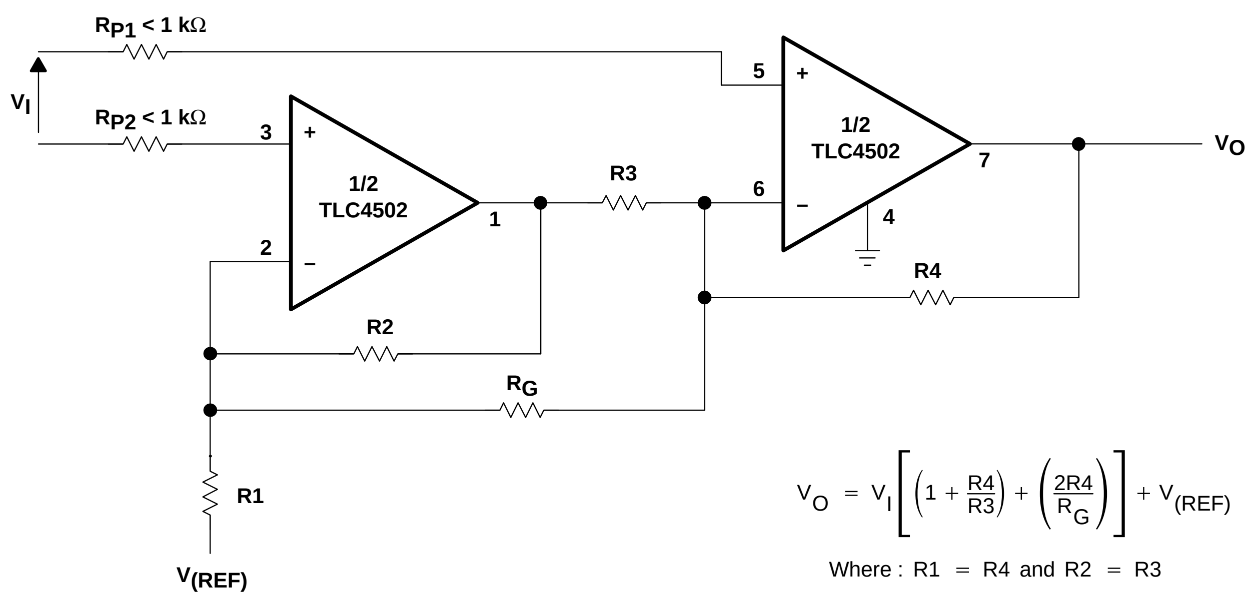
APPLICATION INFORMATION



$$(\text{Gain} = 10) \quad V_O = \left(V_{I1} - V_{I2}\right)\left(1 + \frac{R6}{R4 + R5}\right) + V_{(REF)} \quad \text{Where R1} = \text{R6, R2} = \text{R5, and R3} = \text{R4}$$

$$(\text{Gain} = 100) \quad V_O = \left(V_{I1} - V_{I2}\right)\left(1 + \frac{R5 + R6}{R4}\right) + V_{(REF)} \quad \text{Where R1} = \text{R6, R2} = \text{R5, and R3} = \text{R4}$$

Figure 36. Single-Supply Programmable Instrumentation Amplifier Circuit

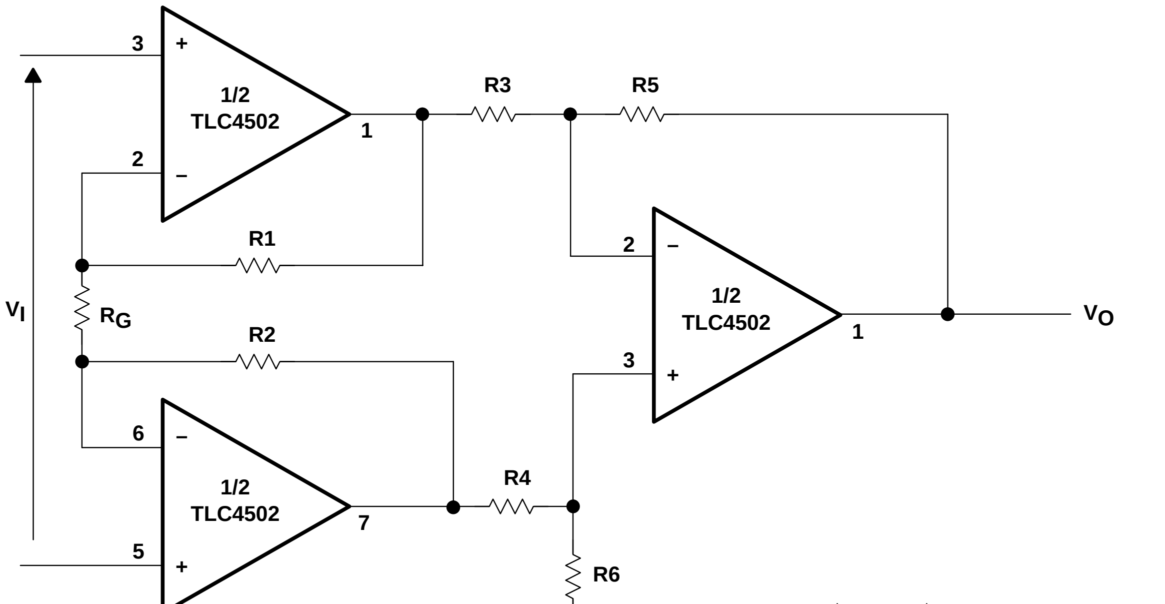


$$V_O = V_I\left[\left(1 + \frac{R4}{R3}\right) + \left(\frac{2R4}{R_G}\right)\right] + V_{(REF)}$$

Where : R1 = R4 and R2 = R3

Figure 37. Two Operational-Amplifier Instrumentation Amplifier Circuit

APPLICATION INFORMATION



$$V_O = V_I\left(\frac{R5}{R3}\right)\left(\frac{2R1}{R_G} + 1\right) + V_{(REF)}$$

Where : R1 = R2, R3 = R4, and R5 = R6

Figure 38. Three Operational-Amplifier Instrumentation Amplifier Circuit

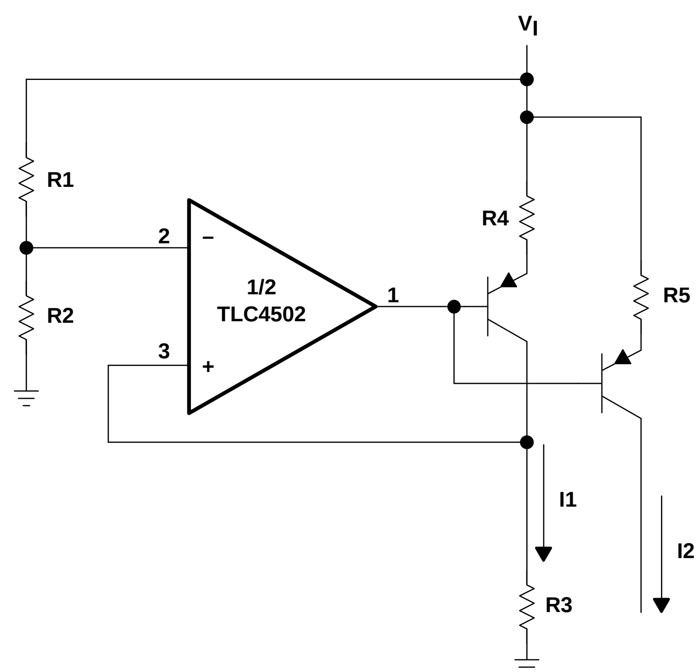


Figure 39. Fixed Current-Source Circuit

APPLICATION INFORMATION

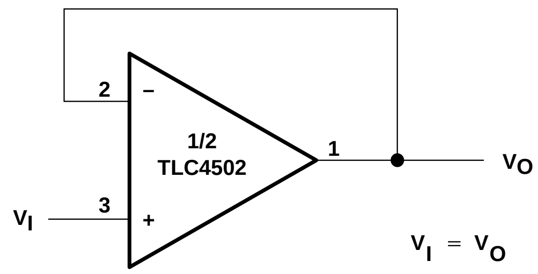


Figure 40. Voltage-Follower Circuit

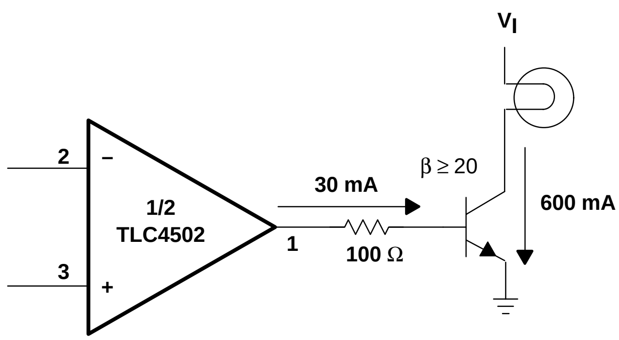


Figure 41. Lamp-Driver Circuit

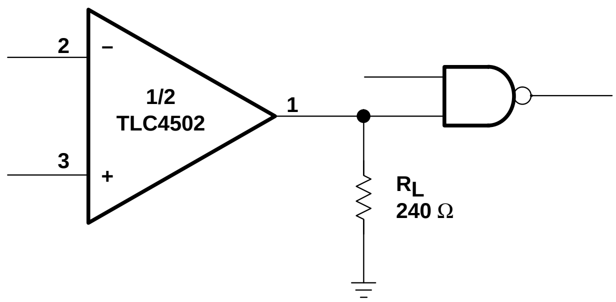


Figure 42. TTL-Driver Circuit

APPLICATION INFORMATION

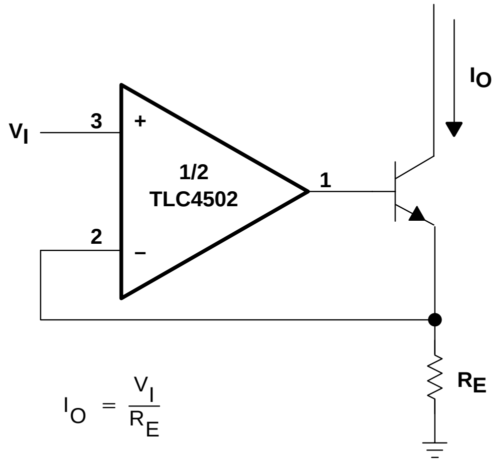


Figure 43. High-Compliance Current-Sink Circuit

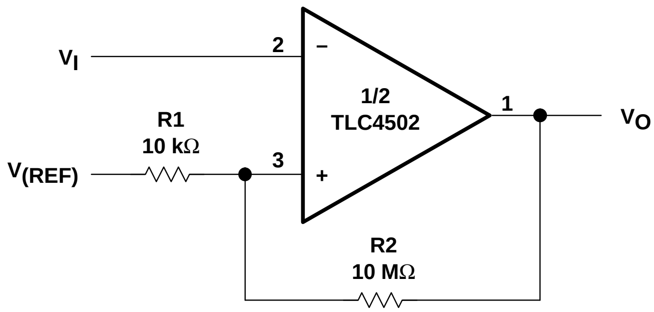


Figure 44. Comparator With Hysteresis Circuit

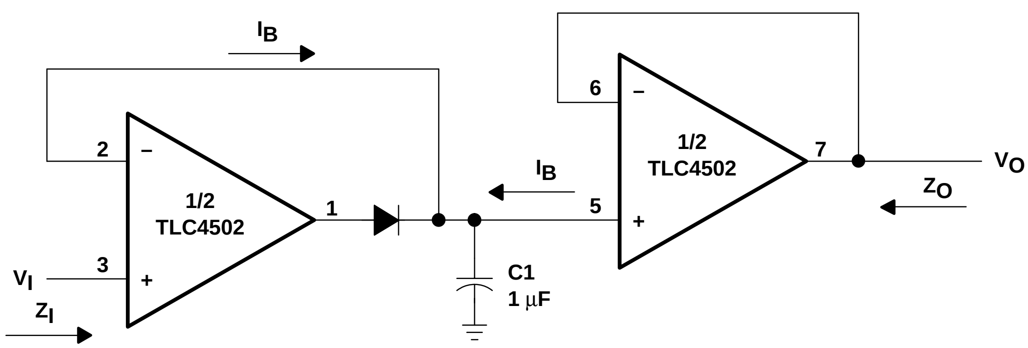


Figure 45. Low-Drift Detector Circuit

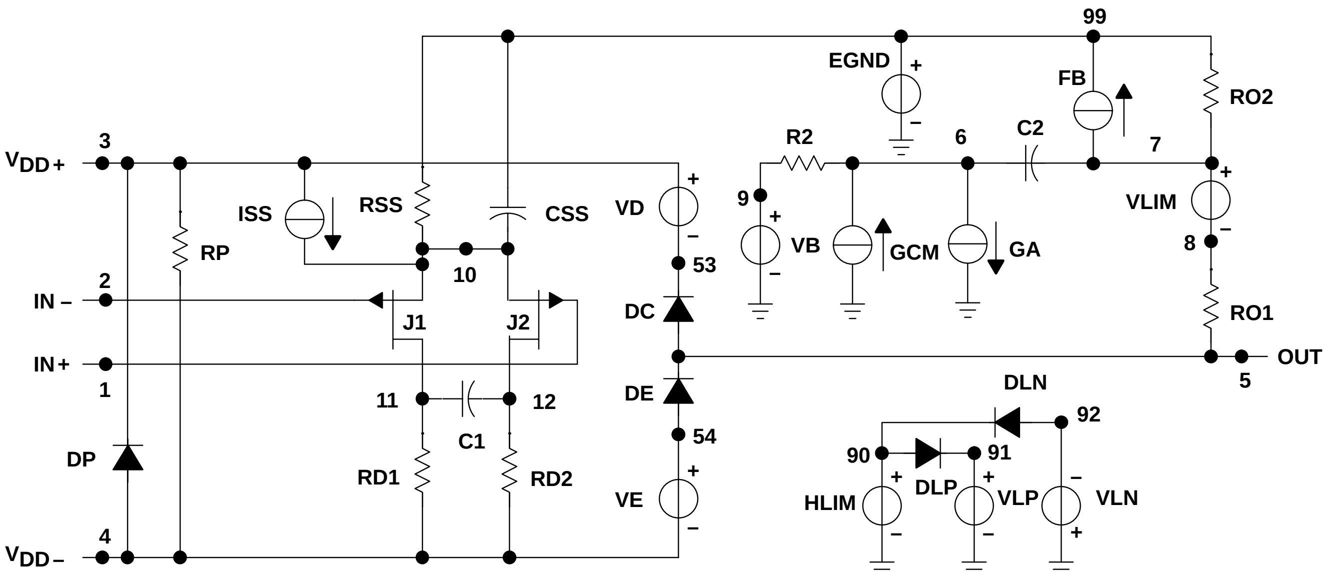
APPLICATION INFORMATION

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°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).




```
.subckt TLC4501  1 2 3 4 5
*
      c1      11    12    1.4559E–12
      c2      6     7     8.0000E–12
      css     10    99    1.0000E–30
      dc      5     53    dy
      de      54    5     dy
      dlp     90    91    dx
      dln     92    90    dx
      dp      4     3     dx
      egnd    99    0     poly(2) (3,0) (4,0) 0 .5 .5
      fb      7     99    poly(5) vb vc ve vlp vln 0
      + 84.657E9 –1E3 1E3 85E9 –85E9
      ga      6     0     11 12 236.25E–6
      gcm     0     6     10 99 2.3625E–9
      iss     10    4     dc 20.000E–6
      hlim    90    0     vlim 1K
      j1      11    2     10 jx1
      j2      12    1     10 jx2
```

```
r2      6     9     100.00E3
rd1     3     11    4.2328E3
rd2     3     12    4.2328E3
ro1     8     5     5.0000E–3
ro2     7     99    5.0000E–3
rp      3     4     5.0000E3
rss     10    99    10.000E6
vb      9     0     dc 0
vc      3     53    dc .92918
ve      54    4     dc .82918
vlim    7     8     dc 0
vlp     91    0     dc 67
vln     0     92    dc 67
.model dx D(Is=800.00E–18)
.model dy D(Is=800.00E–18 Rs=1m Cjo=10p)
.model jx1 NJF(Is=500.00E–15 Beta=2.7907E–3 Vto=–1)
.model jx2 NJF(Is=500.00E–15 Beta=2.7907E–3 Vto=–1)
.ends
```

Figure 46. Boyle Macromodel and Subcircuit

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
5962-9753701QPA	ACTIVE	CDIP	JG	8	1	Non-RoHS & Green	SNPB	N / A for Pkg Type	-55 to 125	9753701QPA TLC4502M	Samples
5962-9753702QHA	ACTIVE	CFP	U	10	1	Non-RoHS & Green	SNPB	N / A for Pkg Type	-55 to 125	9753702QHA TLC4502AM	Samples
5962-9753702QPA	ACTIVE	CDIP	JG	8	1	Non-RoHS & Green	SNPB	N / A for Pkg Type	-55 to 125	9753702QPA TLC4502AM	Samples
TLC4501ACD	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	4501AC	Samples
TLC4501AID	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4501AI	Samples
TLC4501AIDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4501AI	Samples
TLC4501CD	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	4501C	Samples
TLC4501CDG4	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	4501C	Samples
TLC4501ID	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4501I	Samples
TLC4501IDG4	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4501I	Samples
TLC4501IDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4501I	Samples
TLC4502ACD	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	4502AC	Samples
TLC4502ACDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	4502AC	Samples
TLC4502AID	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4502AI	Samples
TLC4502AIDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4502AI	Samples
TLC4502AMD	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-55 to 125	4502AM	Samples
TLC4502AMJGB	ACTIVE	CDIP	JG	8	1	Non-RoHS & Green	SNPB	N / A for Pkg Type	-55 to 125	9753702QPA TLC4502AM	Samples
TLC4502AMUB	ACTIVE	CFP	U	10	1	Non-RoHS & Green	SNPB	N / A for Pkg Type	-55 to 125	9753702QHA TLC4502AM	Samples
TLC4502CD	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	4502C	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLC4502CDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	0 to 70	4502C	Samples
TLC4502ID	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4502I	Samples
TLC4502IDR	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4502I	Samples
TLC4502IDRG4	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	4502I	Samples
TLC4502MDG4	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM		4502M	Samples
TLC4502MJGB	ACTIVE	CDIP	JG	8	1	Non-RoHS & Non-Green	SNPB	N / A for Pkg Type	-55 to 125	9753701QPA TLC4502M	Samples
TLC4502QD	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	C4502Q	Samples
TLC4502QDG4	ACTIVE	SOIC	D	8	75	RoHS & Green	NIPDAU	Level-1-260C-UNLIM		C4502Q	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

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

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

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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

OTHER QUALIFIED VERSIONS OF TLC4502, TLC4502A, TLC4502AM, TLC4502M :

- Catalog : TLC4502A, TLC4502

- Military : TLC4502M, TLC4502AM

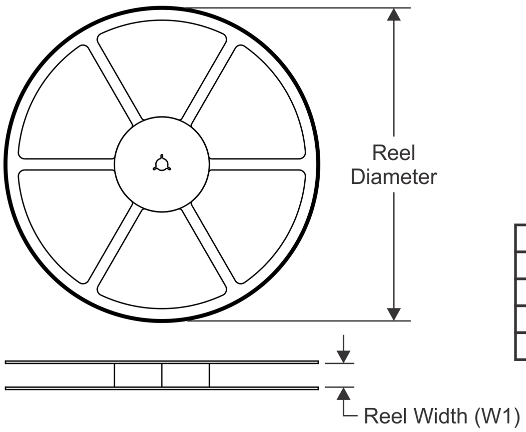
NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product

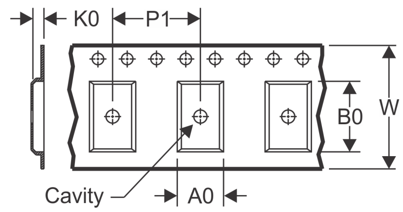
- Military - QML certified for Military and Defense Applications

TAPE AND REEL INFORMATION

REEL DIMENSIONS

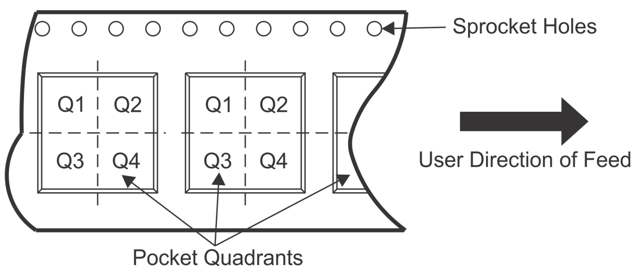


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

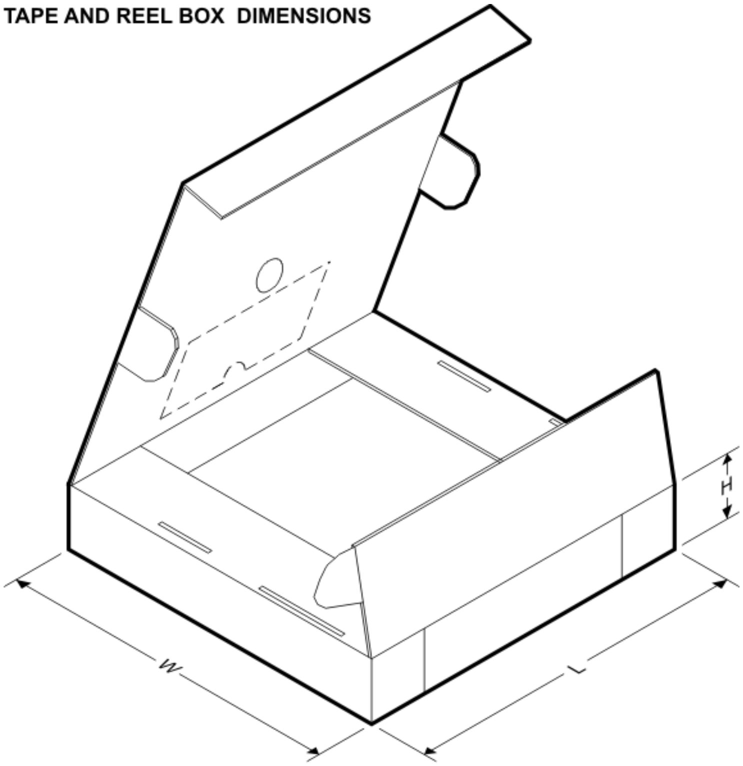
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

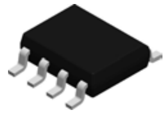
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TLC4501AIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC4501IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC4502ACDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC4502AIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC4502CDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC4502IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

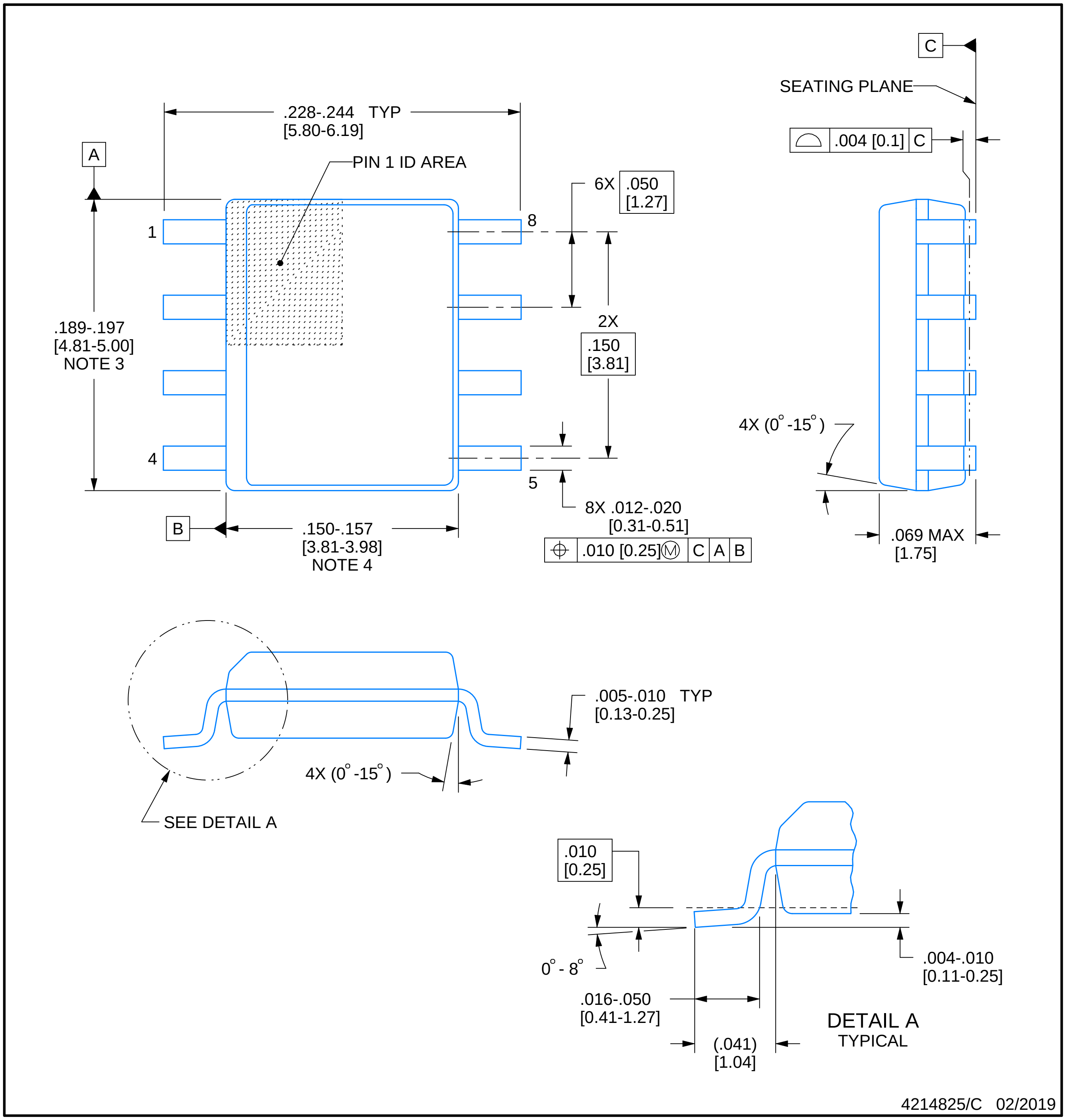
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TLC4501AIDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC4501IDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC4502ACDR	SOIC	D	8	2500	350.0	350.0	43.0
TLC4502AIDR	SOIC	D	8	2500	350.0	350.0	43.0
TLC4502CDR	SOIC	D	8	2500	350.0	350.0	43.0
TLC4502IDR	SOIC	D	8	2500	350.0	350.0	43.0



PACKAGE OUTLINE

SOIC - 1.75 mm max height

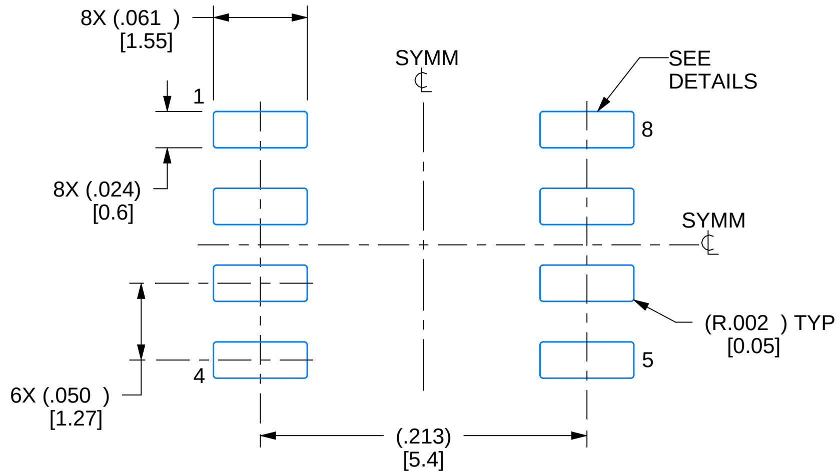
SMALL OUTLINE INTEGRATED CIRCUIT



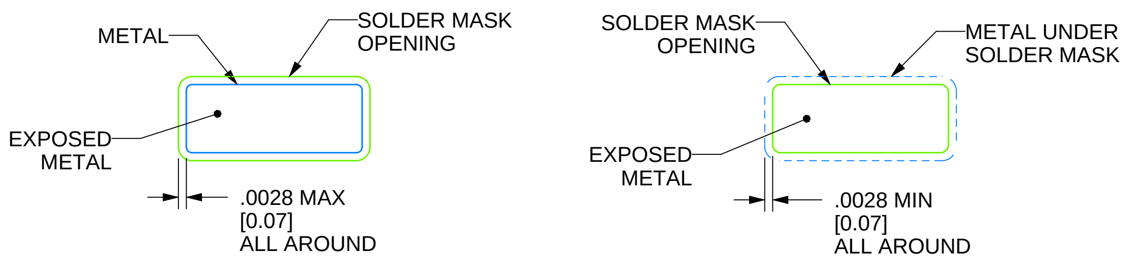
4214825/C 02/2019

NOTES:

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



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X



NON SOLDER MASK
DEFINED

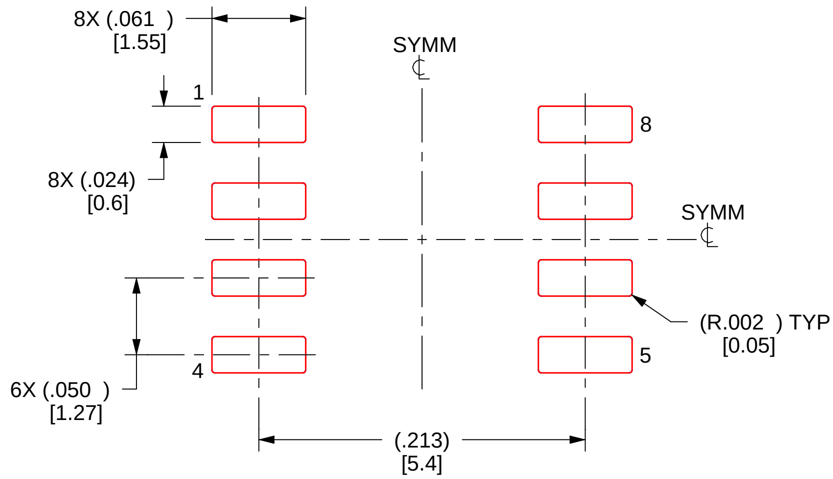
SOLDER MASK
DEFINED

SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

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



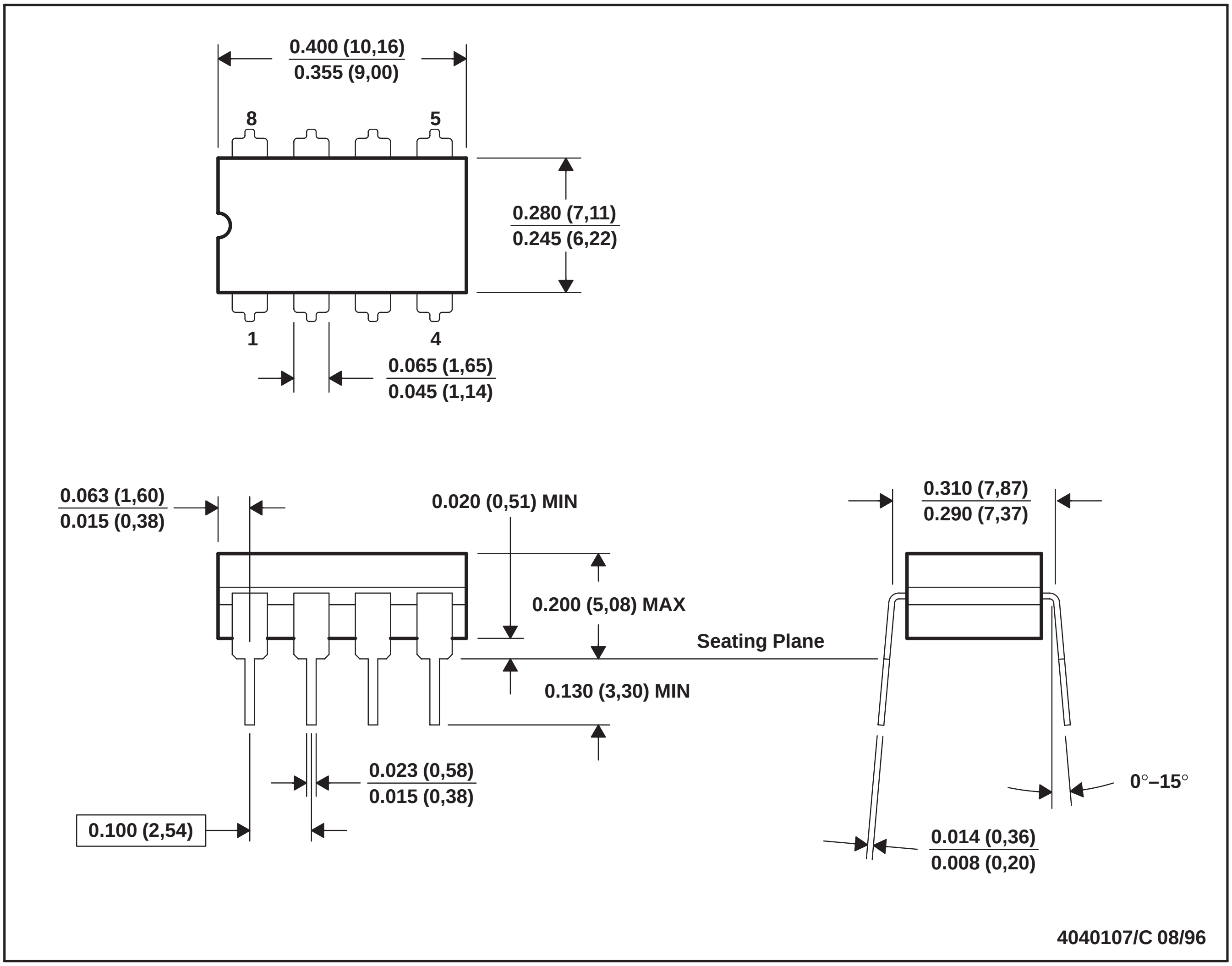
SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

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

JG (R-GDIP-T8) **CERAMIC DUAL-IN-LINE**

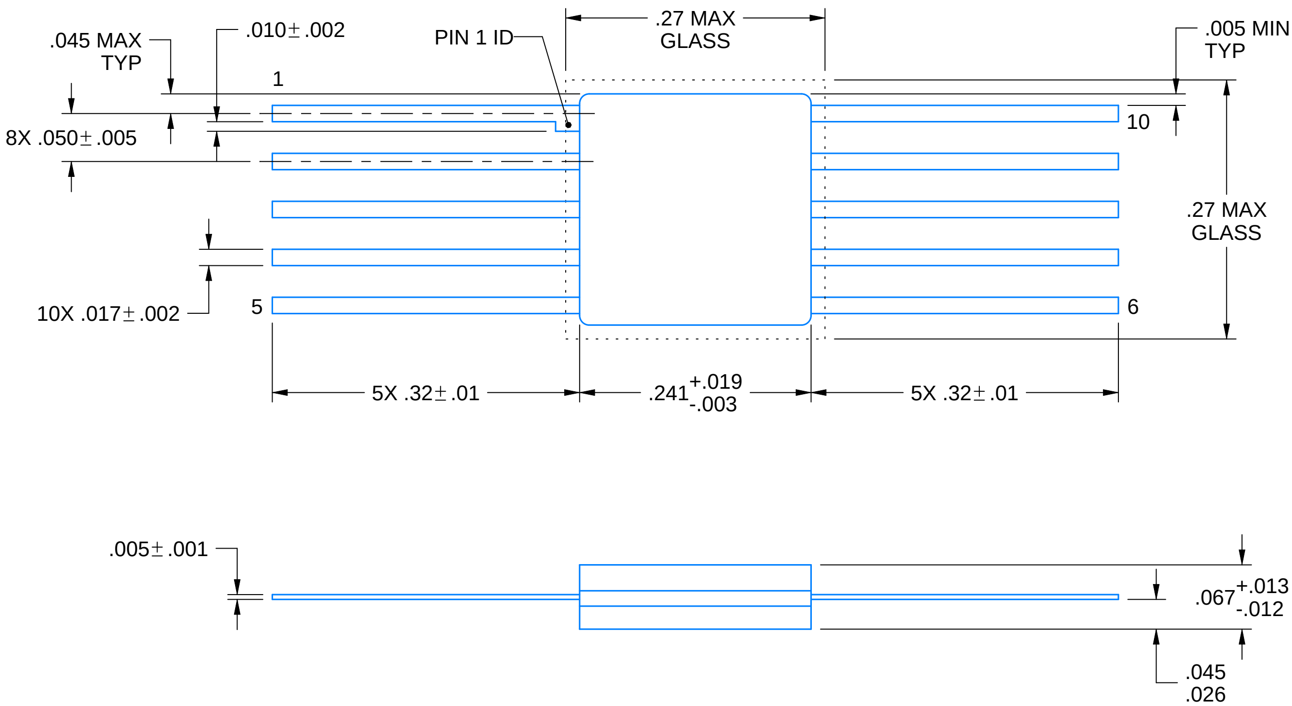


NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a ceramic lid using glass frit.
D. Index point is provided on cap for terminal identification.
E. Falls within MIL STD 1835 GDIP1-T8

PACKAGE OUTLINE

CFP - 2.03 mm max height

CERAMIC FLATPACK



4225582/A 01/2020

NOTES:

1. All linear dimensions are in inches. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.