

# 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.

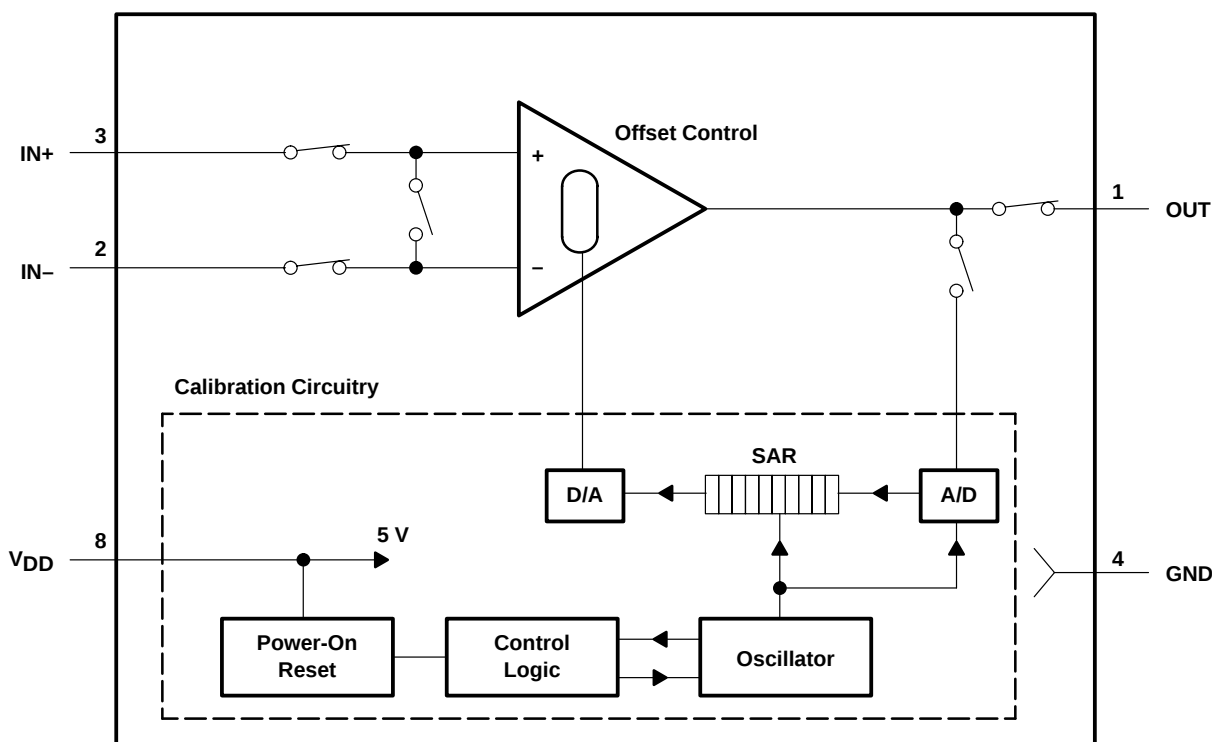


Figure 1. Channel One of the TLC4502



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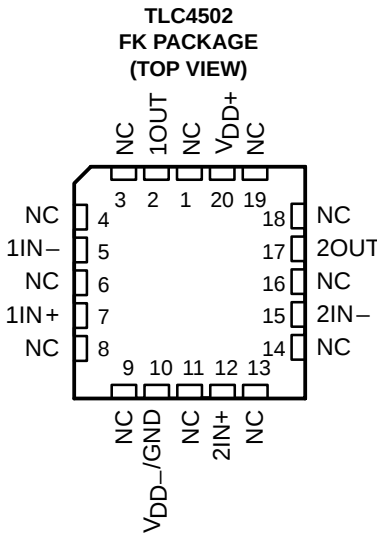
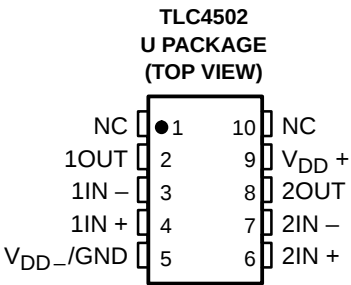
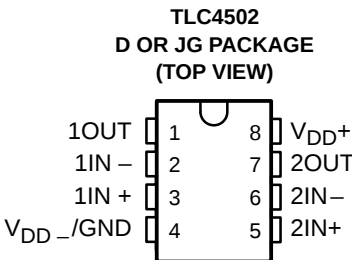
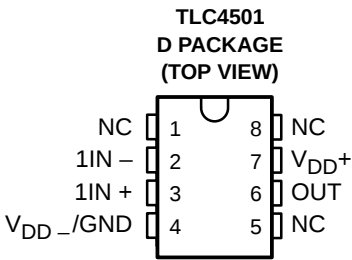
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On products compliant to MIL-PRF-38535, all parameters are tested unless otherwise noted. On all other products, production processing does not necessarily include testing of all parameters.

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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)<sup>†</sup>**

|                                                                   |                              |
|-------------------------------------------------------------------|------------------------------|
| 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                        |

<sup>†</sup> 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 | $T_A \leq 25^\circ\text{C}$<br>POWER RATING | DERATING FACTOR<br>ABOVE $T_A = 25^\circ\text{C}$ | $T_A = 70^\circ\text{C}$<br>POWER RATING | $T_A = 85^\circ\text{C}$<br>POWER RATING | $T_A = 125^\circ\text{C}$<br>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 <sub>A</sub> <sup>†</sup> | TLC450xC         |      |       | UNIT |
|----------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|-------------|-----------------------------|------------------|------|-------|------|
|                      |                                                                       |                                                                                                   |             |                             | MIN              | TYP  | MAX   |      |
| V <sub>IO</sub>      | Input offset voltage                                                  | V <sub>DD</sub> = ±2.5 V,<br>V <sub>IC</sub> = 0,<br>V <sub>O</sub> = 0,<br>R <sub>S</sub> = 50 Ω | TLC4501     | Full range                  | -80              | 10   | 80    | μV   |
|                      |                                                                       |                                                                                                   | TLC4501A    |                             | -40              | 10   | 40    |      |
|                      |                                                                       |                                                                                                   | TLC4502     |                             | -100             | 10   | 100   |      |
|                      |                                                                       |                                                                                                   | TLC4502A    |                             | -50              | 10   | 50    |      |
| α <sub>VIO</sub>     | Temperature coefficient of input offset voltage                       | V <sub>DD</sub> = ±2.5 V,<br>V <sub>IC</sub> = 0,<br>V <sub>O</sub> = 0,<br>R <sub>S</sub> = 50 Ω |             | Full range                  | 1                |      | μV/°C |      |
| I <sub>IO</sub>      | Input offset current                                                  |                                                                                                   |             | 25°C                        | 1 60             |      | pA    |      |
| I <sub>IB</sub>      | Input bias current                                                    |                                                                                                   |             | Full range                  | 500              |      |       |      |
|                      |                                                                       |                                                                                                   |             | 25°C                        | 1 60             |      | pA    |      |
|                      |                                                                       | Full range                                                                                        | 500         |                             |                  |      |       |      |
| V <sub>OH</sub>      | High-level output voltage                                             | I <sub>OH</sub> = − 500 μA                                                                        |             | 25°C                        | 4.99             |      | V     |      |
|                      |                                                                       | I <sub>OH</sub> = − 5 mA                                                                          |             | 25°C                        | 4.9              |      |       |      |
|                      |                                                                       |                                                                                                   |             | Full range                  | 4.7              |      |       |      |
| V <sub>OL</sub>      | Low-level output voltage                                              | V <sub>IC</sub> = 2.5 V, I <sub>OL</sub> = 500 μA                                                 |             | 25°C                        | 0.01             |      | V     |      |
|                      |                                                                       | V <sub>IC</sub> = 2.5 V, I <sub>OL</sub> = 5 mA                                                   |             | 25°C                        | 0.1              |      |       |      |
|                      |                                                                       |                                                                                                   |             | Full range                  | 0.3              |      |       |      |
| A <sub>VD</sub>      | Large-signal differential voltage amplification                       | V <sub>IC</sub> = 2.5 V, R <sub>L</sub> = 1 kΩ, V <sub>O</sub> = 1 V to 4 V, See Note 4           |             | 25°C                        | 200              | 1000 | V/mV  |      |
|                      |                                                                       |                                                                                                   |             | Full range                  | 200              |      |       |      |
| R <sub>I(D)</sub>    | Differential input resistance                                         |                                                                                                   |             | 25°C                        | 10               |      | kΩ    |      |
| R <sub>L</sub>       | Input resistance                                                      | See Note 4                                                                                        |             | 25°C                        | 10 <sup>12</sup> |      | Ω     |      |
| C <sub>L</sub>       | Common-mode input capacitance                                         | f = 10 kHz,                                                                                       | P package   | 25°C                        | 8                |      | pF    |      |
| z <sub>O</sub>       | Closed-loop output impedance                                          | A <sub>V</sub> = 10,                                                                              | f = 100 kHz | 25°C                        | 1                |      | Ω     |      |
| CMRR                 | Common-mode rejection ratio                                           | V <sub>IC</sub> = 0 to 2.7 V, V <sub>O</sub> = 2.5 V, R <sub>S</sub> = 1 kΩ                       |             | 25°C                        | 90               | 100  | dB    |      |
|                      |                                                                       |                                                                                                   |             | Full range                  | 85               |      |       |      |
| k <sub>SVR</sub>     | Supply-voltage rejection ratio (ΔV <sub>DD</sub> ±/ΔV <sub>IO</sub> ) | V <sub>DD</sub> = 4 V to 6 V, V <sub>IC</sub> = 0, No load                                        |             | 25°C                        | 90               | 100  | dB    |      |
|                      |                                                                       |                                                                                                   |             | Full range                  | 90               |      |       |      |
| I <sub>DD</sub>      | Supply current                                                        | V <sub>O</sub> = 2.5 V, No load                                                                   | TLC4501/A   | 25°C                        | 1                | 1.5  | mA    |      |
|                      |                                                                       |                                                                                                   | TLC4502/A   | Full range                  | 2                |      |       |      |
|                      |                                                                       |                                                                                                   |             | 25°C                        | 2.5              | 3.5  |       |      |
|                      |                                                                       |                                                                                                   |             | Full range                  | 4                |      |       |      |
| V <sub>IT(CAL)</sub> | Calibration input threshold voltage                                   |                                                                                                   |             | Full range                  | 4                |      | V     |      |

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

| PARAMETER              |                                             | TEST CONDITIONS                                                                             |                      | T <sub>A</sub> <sup>†</sup>                 | TLC450xC, TLC450xAC |     |     | UNIT   |
|------------------------|---------------------------------------------|---------------------------------------------------------------------------------------------|----------------------|---------------------------------------------|---------------------|-----|-----|--------|
|                        |                                             |                                                                                             |                      |                                             | MIN                 | TYP | MAX |        |
| SR                     | Slew rate at unity gain                     | V <sub>O</sub> = 0.5 V to 2.5 V, C <sub>L</sub> = 100 pF                                    |                      | 25°C                                        | 1.5                 | 2.5 |     | V/μs   |
|                        |                                             |                                                                                             |                      | Full range                                  | 1                   |     |     | V/μs   |
| V <sub>n</sub>         | Equivalent input noise voltage              | f = 10 Hz                                                                                   |                      | 25°C                                        | 70                  |     |     | nV/√Hz |
|                        |                                             | f = 1 kHz                                                                                   |                      | 25°C                                        | 12                  |     |     |        |
| V <sub>N(PP)</sub>     | 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 <sub>n</sub>         | Equivalent input noise current              |                                                                                             |                      | 25°C                                        | 0.6                 |     |     | fA/√Hz |
| THD + N                | Total harmonic distortion plus noise        | V <sub>O</sub> = 0.5 V to 2.5 V, f = 10 kHz, R <sub>L</sub> = 1 kΩ, C <sub>L</sub> = 100 pF | A <sub>V</sub> = 1   | 25°C                                        | 0.02%               |     |     |        |
|                        |                                             |                                                                                             | A <sub>V</sub> = 10  | 25°C                                        | 0.08%               |     |     |        |
|                        |                                             |                                                                                             | A <sub>V</sub> = 100 | 25°C                                        | 0.55%               |     |     |        |
| Gain-bandwidth product |                                             | f = 10 kHz, R <sub>L</sub> = 1 kΩ, C <sub>L</sub> = 100 pF                                  |                      | 25°C                                        | 4.7                 |     |     | MHz    |
| B <sub>OM</sub>        | Maximum output swing bandwidth              | V <sub>O(PP)</sub> = 2 V, R <sub>L</sub> = 1 kΩ                                             |                      | A <sub>V</sub> = 1, C <sub>L</sub> = 100 pF | 25°C                | 1   |     | MHz    |
| t <sub>s</sub>         | Settling time                               | A <sub>V</sub> = −1, Step = 0.5 V to 2.5 V, R <sub>L</sub> = 1 kΩ, C <sub>L</sub> = 100 pF  | to 0.1%              | 25°C                                        | 1.6                 |     |     | μs     |
|                        |                                             |                                                                                             | to 0.01%             | 25°C                                        | 2.2                 |     |     |        |
| φ <sub>m</sub>         | Phase margin at unity gain                  | R <sub>L</sub> = 1 kΩ, C <sub>L</sub> = 100 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 <sub>A</sub> <sup>†</sup> | TLC450xI |      |       | UNIT |
|----------------------|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------|-----------------------------|----------|------|-------|------|
|                      |                                                                       |                                                                                          |               |                             | MIN      | TYP  | MAX   |      |
| V <sub>IO</sub>      | Input offset voltage                                                  | V <sub>DD</sub> = ±2.5 V, V <sub>O</sub> = 0, V <sub>IC</sub> = 0, R <sub>S</sub> = 50 Ω | TLC4501       | Full range                  | –80      | 10   | 80    | μV   |
|                      |                                                                       |                                                                                          | TLC4501A      |                             | –40      | 10   | 40    |      |
|                      |                                                                       |                                                                                          | TLC4502       |                             | –100     | 10   | 100   |      |
|                      |                                                                       |                                                                                          | TLC4502A      |                             | –50      | 10   | 50    |      |
| αV <sub>IO</sub>     | Temperature coefficient of input offset voltage                       | V <sub>DD</sub> = ±2.5 V, V <sub>O</sub> = 0, V <sub>IC</sub> = 0, R <sub>S</sub> = 50 Ω |               | Full range                  | 1        |      | μV/°C |      |
| I <sub>IO</sub>      | Input offset current                                                  |                                                                                          |               | 25°C                        | 1 60     |      | pA    |      |
|                      |                                                                       |                                                                                          |               | –40°C to 85°C               | 500      |      |       |      |
|                      |                                                                       |                                                                                          |               | Full range                  | 5        |      | nA    |      |
| I <sub>IB</sub>      | Input bias current                                                    | V <sub>DD</sub> = ±2.5 V, V <sub>O</sub> = 0, V <sub>IC</sub> = 0, R <sub>S</sub> = 50 Ω | 25°C          | 1 60                        |          | pA   |       |      |
|                      |                                                                       |                                                                                          | –40°C to 85°C | 500                         |          |      |       |      |
|                      |                                                                       |                                                                                          | Full range    | 10                          |          | nA   |       |      |
| V <sub>OH</sub>      | High-level output voltage                                             | I <sub>OH</sub> = – 500 μA                                                               | 25°C          | 4.99                        |          | V    |       |      |
|                      |                                                                       | I <sub>OH</sub> = – 5 mA                                                                 | 25°C          | 4.9                         |          |      |       |      |
|                      |                                                                       |                                                                                          | Full range    | 4.7                         |          |      |       |      |
| V <sub>OL</sub>      | Low-level output voltage                                              | V <sub>IC</sub> = 2.5 V, I <sub>OL</sub> = 500 μA                                        | 25°C          | 0.01                        |          | V    |       |      |
|                      |                                                                       | V <sub>IC</sub> = 2.5 V, I <sub>OL</sub> = 5 mA                                          | 25°C          | 0.1                         |          |      |       |      |
|                      |                                                                       |                                                                                          | Full range    | 0.3                         |          |      |       |      |
| A <sub>VD</sub>      | Large-signal differential voltage amplification                       | V <sub>IC</sub> = 2.5 V, R <sub>L</sub> = 1 kΩ, V <sub>O</sub> = 1 V to 4 V, See Note 4  | 25°C          | 200                         | 1000     | V/mV |       |      |
|                      |                                                                       |                                                                                          | Full range    | 200                         |          |      |       |      |
| R <sub>I(D)</sub>    | Differential input resistance                                         |                                                                                          | 25°C          | 10                          |          | kΩ   |       |      |
| R <sub>L</sub>       | Input resistance                                                      | See Note 4                                                                               | 25°C          | 10 <sup>12</sup>            |          | Ω    |       |      |
| C <sub>L</sub>       | Common-mode input capacitance                                         | f = 10 kHz, P package                                                                    | 25°C          | 8                           |          | pF   |       |      |
| z <sub>O</sub>       | Closed-loop output impedance                                          | A <sub>V</sub> = 10, f = 100 kHz                                                         | 25°C          | 1                           |          | Ω    |       |      |
| CMRR                 | Common-mode rejection ratio                                           | V <sub>IC</sub> = 0 to 2.7 V, V <sub>O</sub> = 2.5 V, R <sub>S</sub> = 1 kΩ              | 25°C          | 90                          | 100      | dB   |       |      |
|                      |                                                                       |                                                                                          | Full range    | 85                          |          |      |       |      |
| k <sub>SVR</sub>     | Supply-voltage rejection ratio (ΔV <sub>DD</sub> ± ΔV <sub>IO</sub> ) | V <sub>DD</sub> = 4 V to 6 V, V <sub>IC</sub> = 0, No load                               | 25°C          | 90                          | 100      | dB   |       |      |
|                      |                                                                       |                                                                                          | Full range    | 90                          |          |      |       |      |
| I <sub>DD</sub>      | Supply current                                                        | V <sub>O</sub> = 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 <sub>IT(CAL)</sub> | Calibration input threshold voltage                                   |                                                                                          | Full range    | 4                           |          | V    |       |      |

$^\dagger$  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 <sub>A</sub> <sup>†</sup> | TLC450xI, TLC450xAI |     |     | UNIT   |
|------------------------|---------------------------------------------|---------------------------------------------------------------------------------------------|---------------------------------------------|-----------------------------|---------------------|-----|-----|--------|
|                        |                                             |                                                                                             |                                             |                             | MIN                 | TYP | MAX |        |
| SR                     | Slew rate at unity gain                     | V <sub>O</sub> = 0.5 V to 2.5 V, C <sub>L</sub> = 100 pF                                    |                                             | 25°C                        | 1.5                 | 2.5 |     | V/μs   |
|                        |                                             |                                                                                             |                                             | Full range                  | 1                   |     |     | V/μs   |
| V <sub>n</sub>         | Equivalent input noise voltage              | f = 10 Hz                                                                                   |                                             | 25°C                        | 70                  |     |     | nV/√Hz |
|                        |                                             | f = 1 kHz                                                                                   |                                             | 25°C                        | 12                  |     |     |        |
| V <sub>N(PP)</sub>     | 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 <sub>n</sub>         | Equivalent input noise current              |                                                                                             |                                             | 25°C                        | 0.6                 |     |     | fA/√Hz |
| THD + N                | Total harmonic distortion plus noise        | V <sub>O</sub> = 0.5 V to 2.5 V, f = 10 kHz, R <sub>L</sub> = 1 kΩ, C <sub>L</sub> = 100 pF | A <sub>V</sub> = 1                          | 25°C                        | 0.02%               |     |     |        |
|                        |                                             |                                                                                             | A <sub>V</sub> = 10                         | 25°C                        | 0.08%               |     |     |        |
|                        |                                             |                                                                                             | A <sub>V</sub> = 100                        | 25°C                        | 0.55%               |     |     |        |
| Gain-bandwidth product |                                             | f = 10 kHz, C <sub>L</sub> = 100 pF                                                         | R <sub>L</sub> = 1 kΩ,                      | 25°C                        | 4.7                 |     |     | MHz    |
| B <sub>OM</sub>        | Maximum output swing bandwidth              | V <sub>O(PP)</sub> = 2 V, R <sub>L</sub> = 1 kΩ,                                            | A <sub>V</sub> = 1, C <sub>L</sub> = 100 pF | 25°C                        | 1                   |     |     | MHz    |
| t <sub>s</sub>         | Settling time                               | A <sub>V</sub> = −1, Step = 0.5 V to 2.5 V, R <sub>L</sub> = 1 kΩ, C <sub>L</sub> = 100 pF  | to 0.1%                                     | 25°C                        | 1.6                 |     |     | μs     |
|                        |                                             |                                                                                             | to 0.01%                                    | 25°C                        | 2.2                 |     |     |        |
| φ <sub>m</sub>         | Phase margin at unity gain                  | R <sub>L</sub> = 1 kΩ,                                                                      | C <sub>L</sub> = 100 pF                     | 25°C                        | 74                  |     |     |        |
| Calibration time       |                                             |                                                                                             |                                             | 25°C                        | 300                 |     |     | ms     |

$^\dagger$  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 <sub>A</sub> <sup>†</sup> | TLC4502Q,<br>TLC4502M |             |          | UNIT      |       |
|----------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------------------------|----------------------------------------------|-----------------------------|-----------------------|-------------|----------|-----------|-------|
|                      |                                                                       |                                                                                         |                                              |                             | MIN                   | TYP         | MAX      |           |       |
| V <sub>IO</sub>      | Input offset voltage                                                  | V <sub>DD</sub> = ±2.5 V,<br>V <sub>IC</sub> = 0,                                       | V <sub>O</sub> = 0,<br>R <sub>S</sub> = 50 Ω | TLC4502<br>TLC4502A         | Full range            | –100<br>–50 | 10<br>10 | 100<br>50 | μV    |
| α <sub>VIO</sub>     | Temperature coefficient of input offset voltage                       | V <sub>DD</sub> = ±2.5 V,<br>V <sub>IC</sub> = 0,<br>R <sub>S</sub> = 50 Ω              |                                              |                             | Full range            | 1           |          |           | μV/°C |
| I <sub>IO</sub>      | Input offset current                                                  |                                                                                         |                                              |                             | 25°C                  | 1           |          | 60        | nA    |
|                      |                                                                       |                                                                                         |                                              |                             | 125°C                 |             |          | 5         |       |
| I <sub>IB</sub>      | Input bias current                                                    |                                                                                         |                                              |                             | 25°C                  | 1           |          | 60        | nA    |
|                      |                                                                       |                                                                                         |                                              |                             | 125°C                 |             |          | 10        |       |
| V <sub>OH</sub>      | High-level output voltage                                             | I <sub>OH</sub> = – 500 μA                                                              |                                              | 25°C                        | 4.99                  |             | V        |           |       |
|                      |                                                                       | I <sub>OH</sub> = – 5 mA                                                                |                                              | 25°C                        | 4.9                   |             |          |           |       |
|                      |                                                                       |                                                                                         |                                              | Full range                  | 4.7                   |             |          |           |       |
| V <sub>OL</sub>      | Low-level output voltage                                              | V <sub>IC</sub> = 2.5 V, I <sub>OL</sub> = 500 μA                                       |                                              | 25°C                        | 0.01                  |             | V        |           |       |
|                      |                                                                       | V <sub>IC</sub> = 2.5 V, I <sub>OL</sub> = 5 mA                                         |                                              | 25°C                        | 0.1                   |             |          |           |       |
|                      |                                                                       |                                                                                         |                                              | Full range                  | 0.3                   |             |          |           |       |
| A <sub>VD</sub>      | Large-signal differential voltage amplification                       | V <sub>IC</sub> = 2.5 V, R <sub>L</sub> = 1 kΩ, V <sub>O</sub> = 1 V to 4 V, See Note 4 |                                              | 25°C                        | 200                   | 1000        | V/mV     |           |       |
|                      |                                                                       |                                                                                         |                                              | Full range                  | 200                   |             |          |           |       |
| R <sub>I(D)</sub>    | Differential input resistance                                         |                                                                                         |                                              | 25°C                        | 10                    |             | kΩ       |           |       |
| R <sub>L</sub>       | Input resistance                                                      | See Note 4                                                                              |                                              | 25°C                        | 10 <sup>12</sup>      |             | Ω        |           |       |
| C <sub>L</sub>       | Common-mode input capacitance                                         | f = 10 kHz, P package                                                                   |                                              | 25°C                        | 8                     |             | pF       |           |       |
| z <sub>O</sub>       | Closed-loop output impedance                                          | A <sub>V</sub> = 10, f = 100 kHz                                                        |                                              | 25°C                        | 1                     |             | Ω        |           |       |
| CMRR                 | Common-mode rejection ratio                                           | V <sub>IC</sub> = 0 to 2.7 V, V <sub>O</sub> = 2.5 V, R <sub>S</sub> = 1 kΩ             |                                              | 25°C                        | 90                    | 100         | dB       |           |       |
|                      |                                                                       |                                                                                         |                                              | Full range                  | 85                    |             |          |           |       |
| k <sub>SVR</sub>     | Supply-voltage rejection ratio (ΔV <sub>DD</sub> ±/ΔV <sub>IO</sub> ) | V <sub>DD</sub> = 4 V to 6 V, V <sub>IC</sub> = V <sub>DD</sub> /2, No load             |                                              | 25°C                        | 90                    | 100         | dB       |           |       |
|                      |                                                                       |                                                                                         |                                              | Full range                  | 90                    |             |          |           |       |
| I <sub>DD</sub>      | Supply current                                                        | V <sub>O</sub> = 2.5 V, No load                                                         |                                              | 25°C                        | 2.5                   | 3.5         | mA       |           |       |
|                      |                                                                       |                                                                                         |                                              | Full range                  | 4                     |             |          |           |       |
| V <sub>IT(CAL)</sub> | Calibration input threshold voltage                                   |                                                                                         |                                              | Full range                  | 4                     |             | V        |           |       |

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

| PARAMETER                                               | TEST CONDITIONS                                                                                                     | $T_A^\dagger$      | TLC4502Q, TLC4502M,<br>TLC4502AQ,<br>TLC4502AM |       |     | UNIT                         |
|---------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|--------------------|------------------------------------------------|-------|-----|------------------------------|
|                                                         |                                                                                                                     |                    | MIN                                            | TYP   | MAX |                              |
| SR      Slew rate at unity gain                         | $V_O = 0.5\text{ V to }2.5\text{ V},$<br>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    |     | $\text{nV}/\sqrt{\text{Hz}}$ |
|                                                         | $f = 1\text{ kHz}$                                                                                                  | 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   |     | $\text{fA}/\sqrt{\text{Hz}}$ |
| THD + N      Total harmonic distortion plus noise       | $V_O = 0.5\text{ V to }2.5\text{ V},$<br>$f = 10\text{ kHz},$<br>$R_L = 1\text{ k}\Omega,$<br>$C_L = 100\text{ pF}$ | $A_V = 1$ 25°C     |                                                | 0.02% |     |                              |
|                                                         |                                                                                                                     | $A_V = 10$ 25°C    |                                                | 0.08% |     |                              |
|                                                         |                                                                                                                     | $A_V = 100$ 25°C   |                                                | 0.55% |     |                              |
| Gain-bandwidth product                                  | $f = 10\text{ kHz},$ $R_L = 1\text{ k}\Omega,$<br>$C_L = 100\text{ pF}$                                             | 25°C               |                                                | 4.7   |     | MHz                          |
| $B_{OM}$ Maximum output swing bandwidth                 | $V_{O(PP)} = 2\text{ V},$ $A_V = 1,$<br>$R_L = 1\text{ k}\Omega,$ $C_L = 100\text{ pF}$                             | 25°C               |                                                | 1     |     | MHz                          |
| $t_s$ Settling time                                     | $A_V = -1,$<br>Step = $0.5\text{ V to }2.5\text{ V},$<br>$R_L = 1\text{ k}\Omega,$<br>$C_L = 100\text{ pF}$         | 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  $-40^\circ\text{C}$  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            |
|                 |                                                 | vs Free-air temperature       | 27            |
| $\phi_m$        | Phase margin                                    | vs Load capacitance           | 28            |
|                 |                                                 | vs Frequency                  | 14            |
|                 | Gain margin                                     | vs Load capacitance           | 29            |
|                 |                                                 | vs Frequency                  | 30            |
| 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            |



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## TYPICAL CHARACTERISTICS

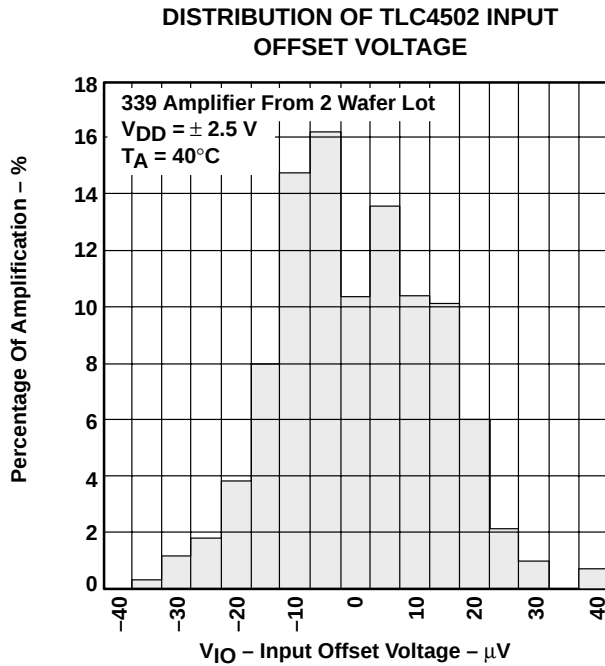


Figure 2

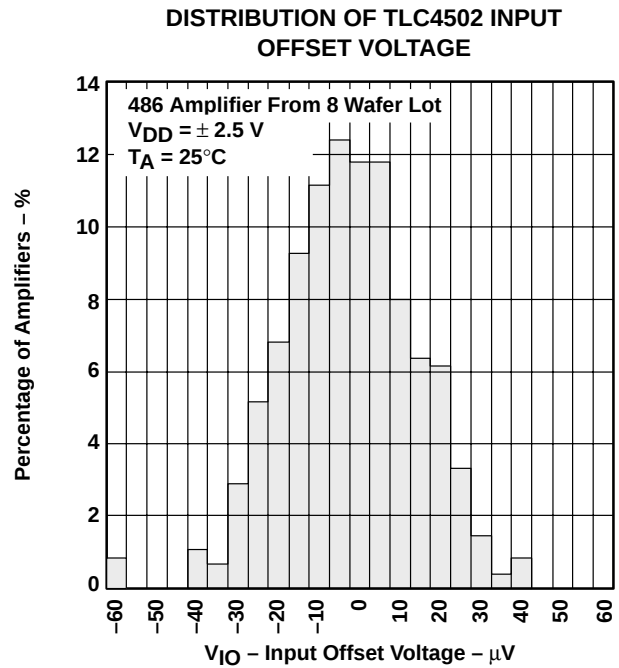


Figure 3

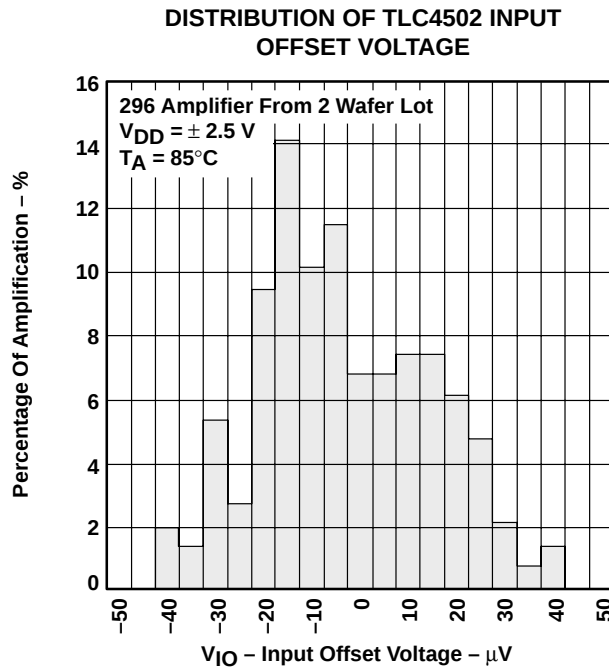


Figure 4

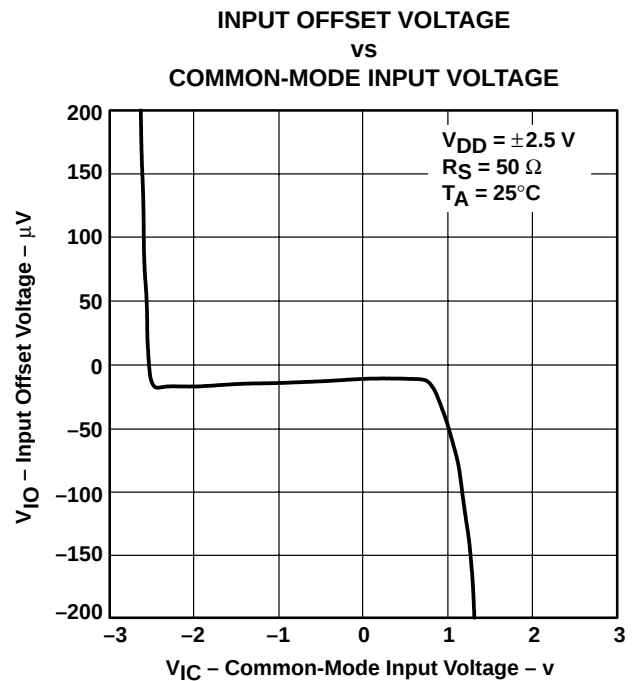


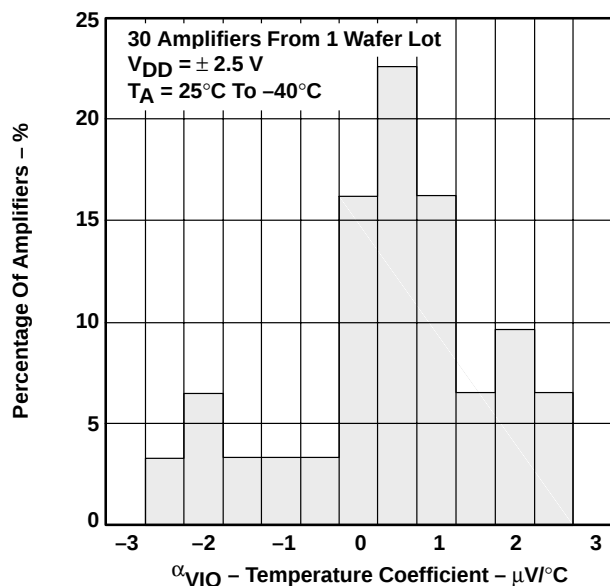
Figure 5

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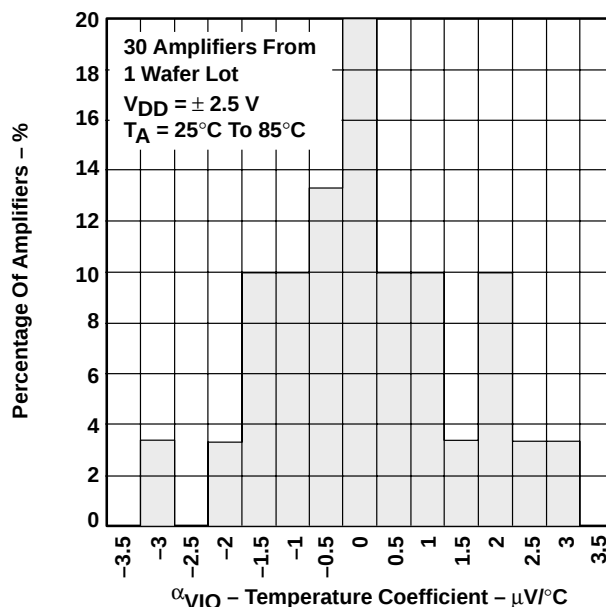
**TYPICAL CHARACTERISTICS**

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



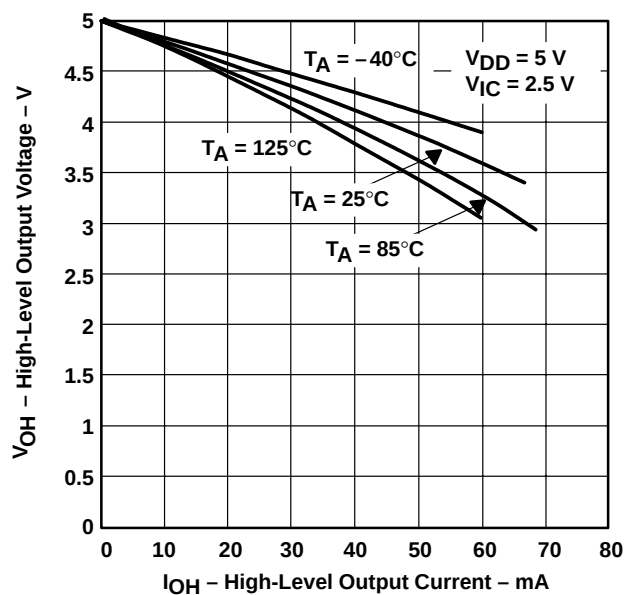
**Figure 6**

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



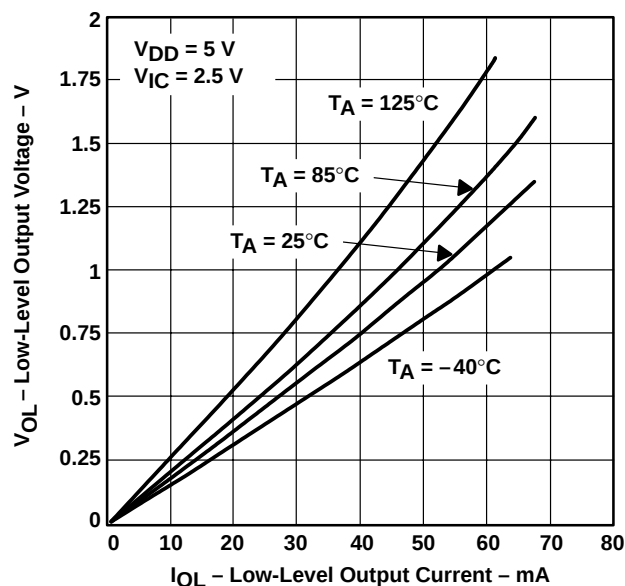
**Figure 7**

**HIGH-LEVEL OUTPUT VOLTAGE VS HIGH-LEVEL OUTPUT CURRENT**



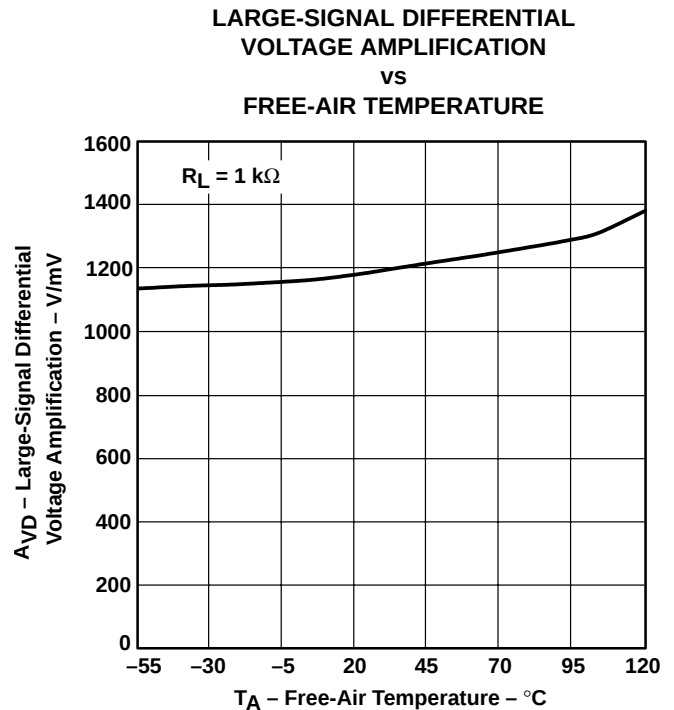
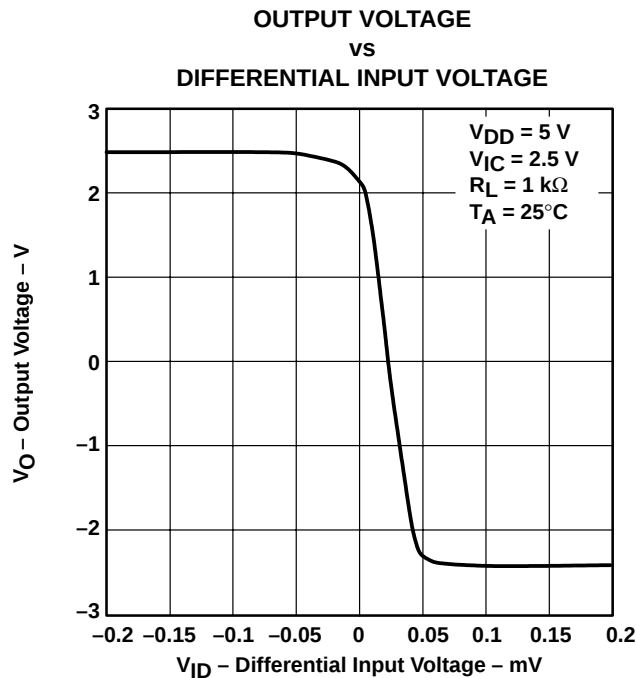
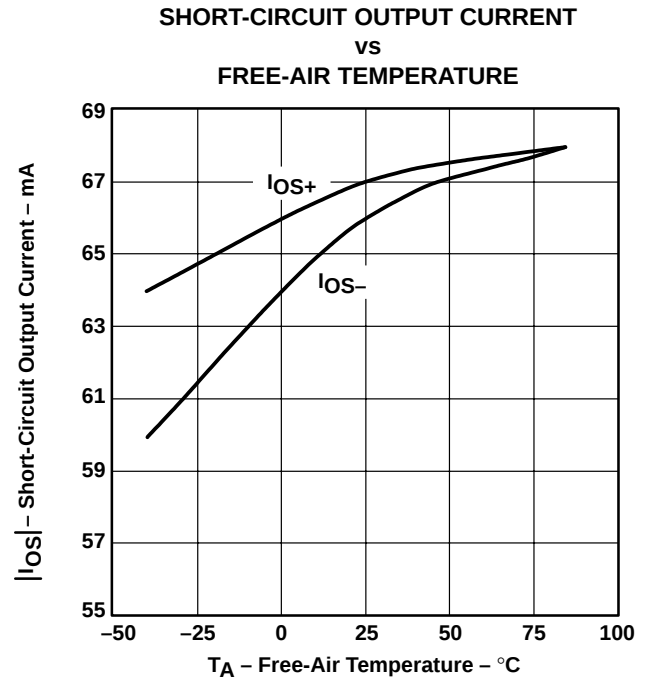
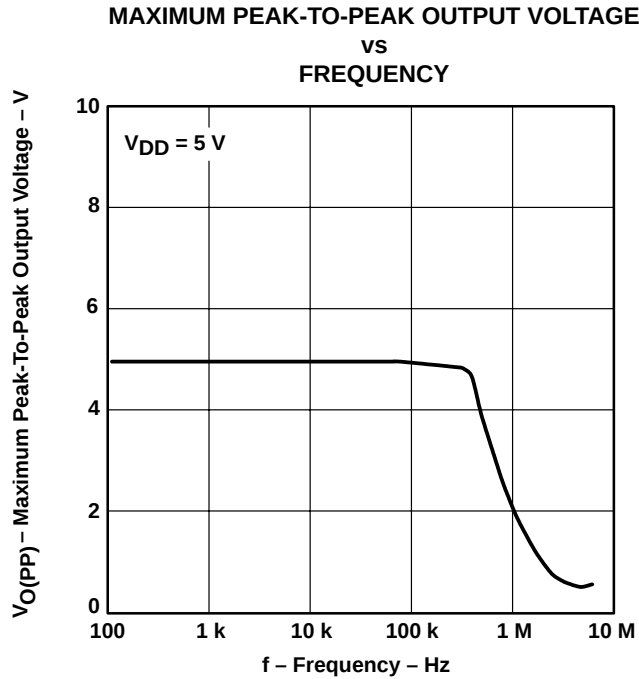
**Figure 8**

**LOW-LEVEL OUTPUT VOLTAGE VS LOW-LEVEL OUTPUT CURRENT**



**Figure 9**

## TYPICAL CHARACTERISTICS



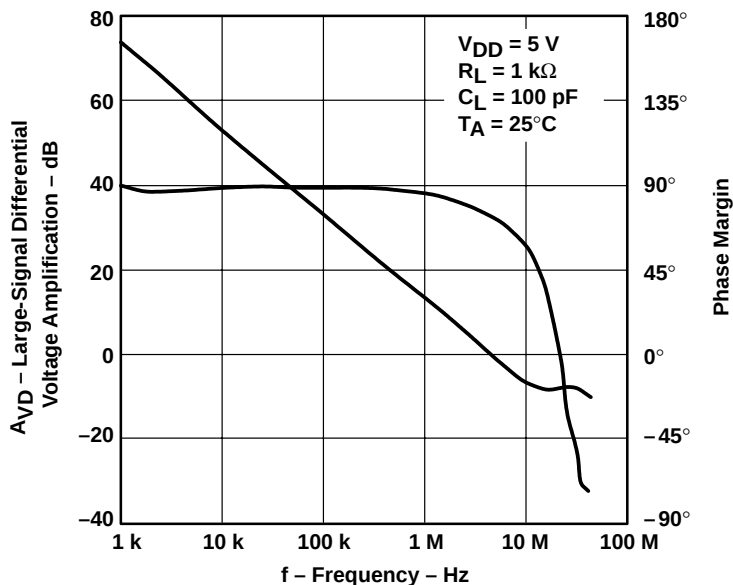
**TLC4501, TLC4501A, TLC4502, TLC4502A**  
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**TYPICAL CHARACTERISTICS**

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

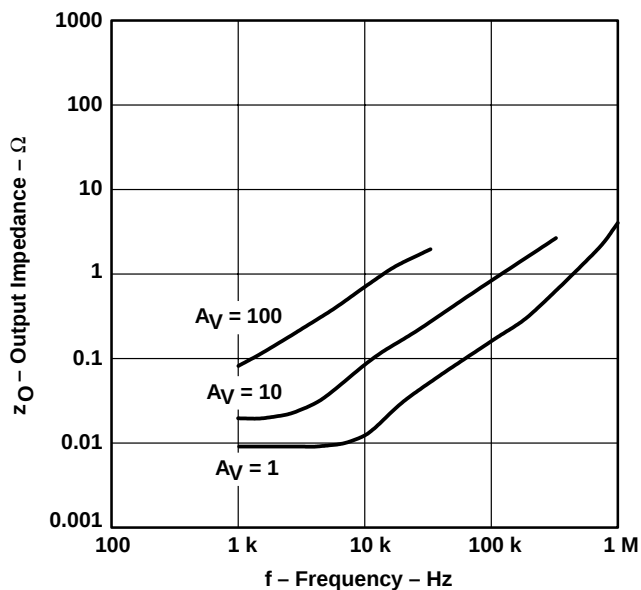
**VS  
FREQUENCY**



**Figure 14**

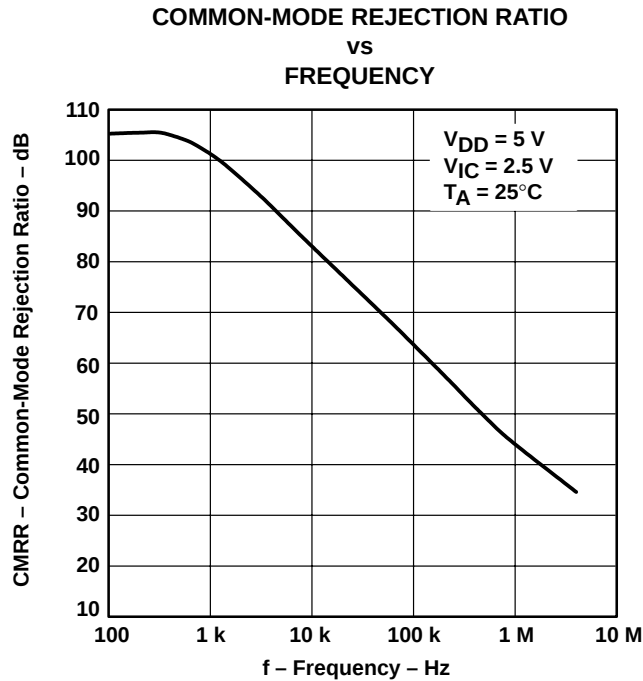
**OUTPUT IMPEDANCE**

**VS  
FREQUENCY**

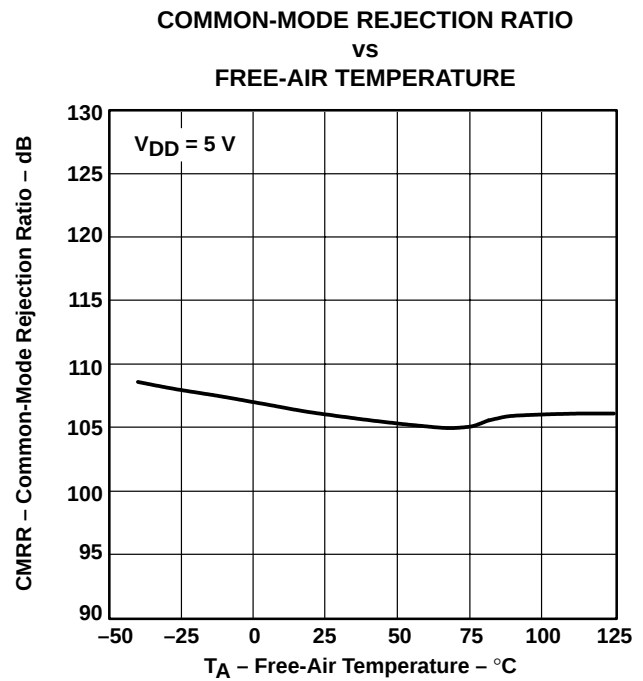


**Figure 15**

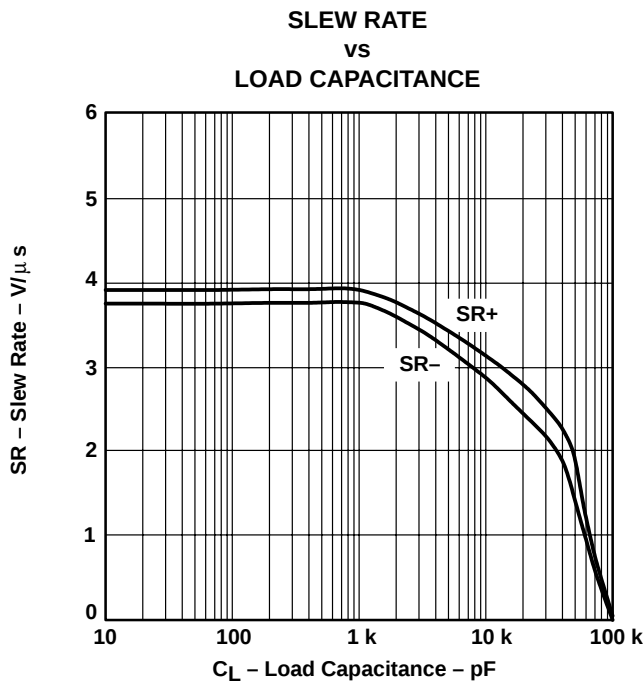
## TYPICAL CHARACTERISTICS



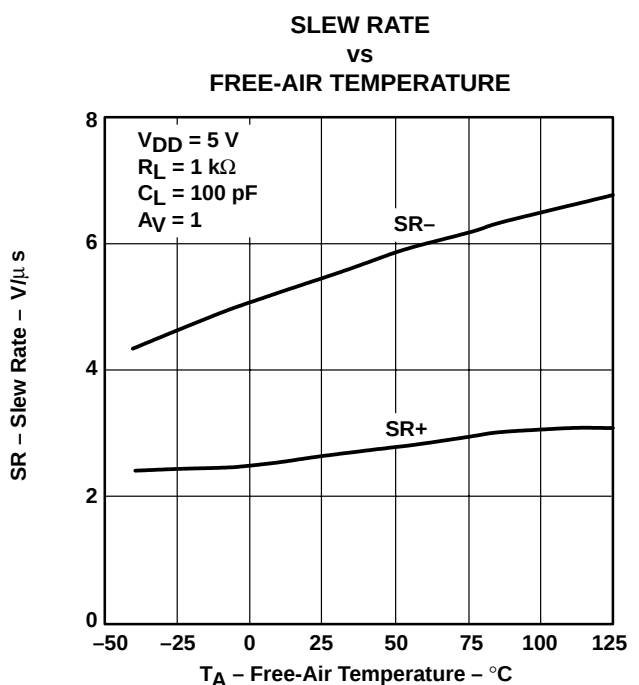
**Figure 16**



**Figure 17**



**Figure 18**



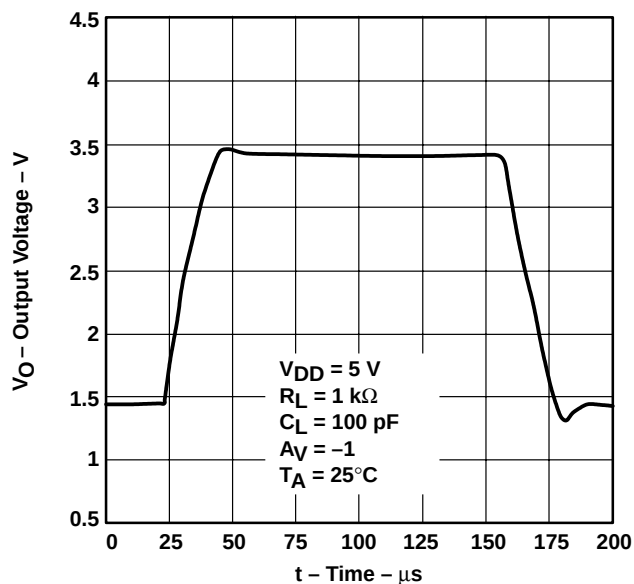
**Figure 19**

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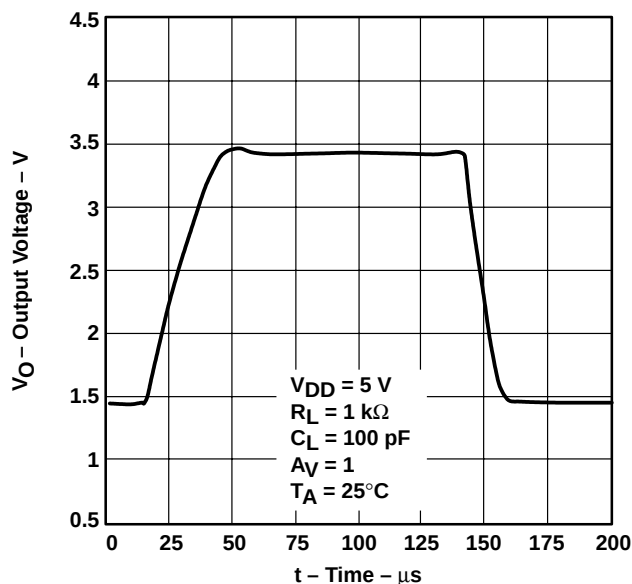
**TYPICAL CHARACTERISTICS**

**INVERTING LARGE-SIGNAL PULSE RESPONSE**



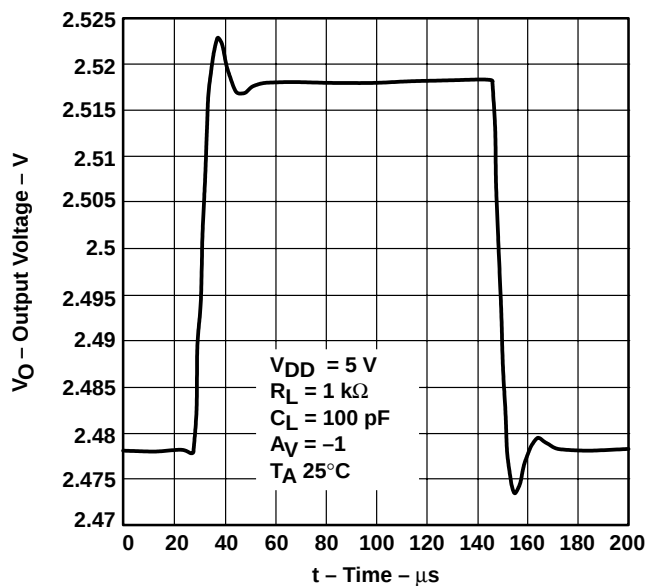
**Figure 20**

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



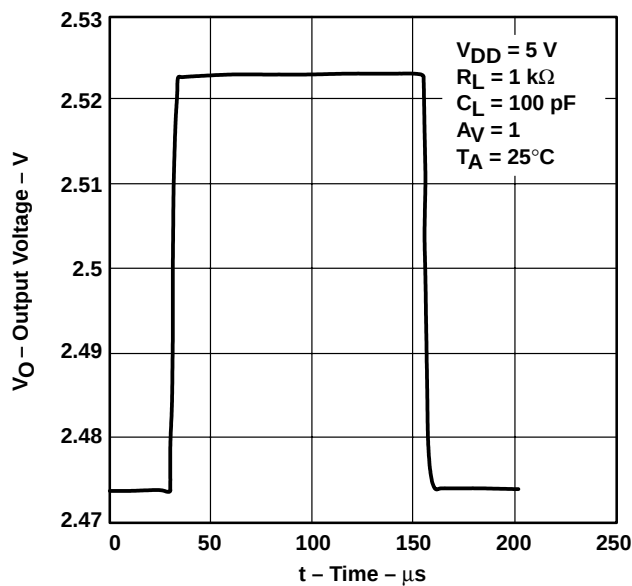
**Figure 21**

**INVERTING SMALL-SIGNAL PULSE RESPONSE**



**Figure 22**

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



**Figure 23**

## TYPICAL CHARACTERISTICS

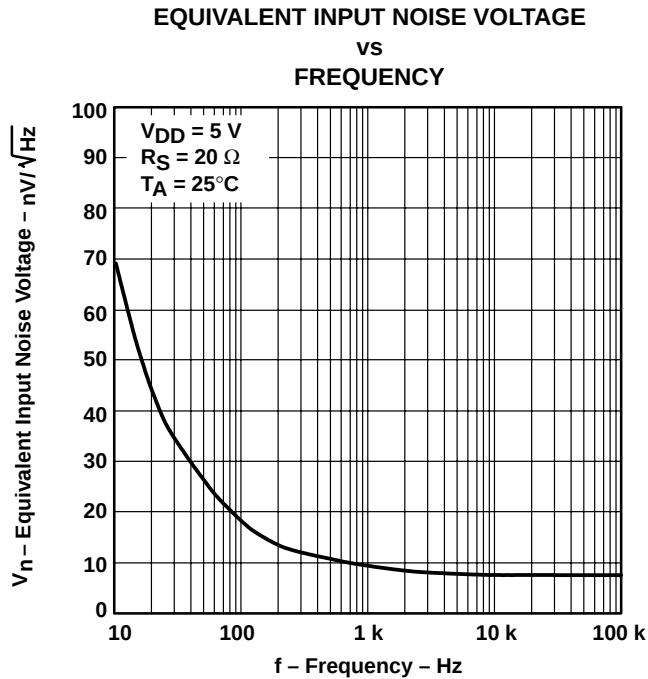


Figure 24

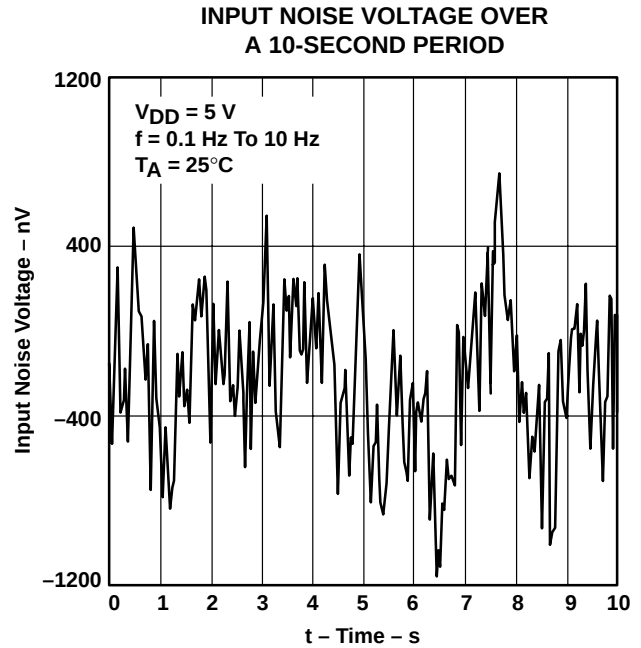


Figure 25

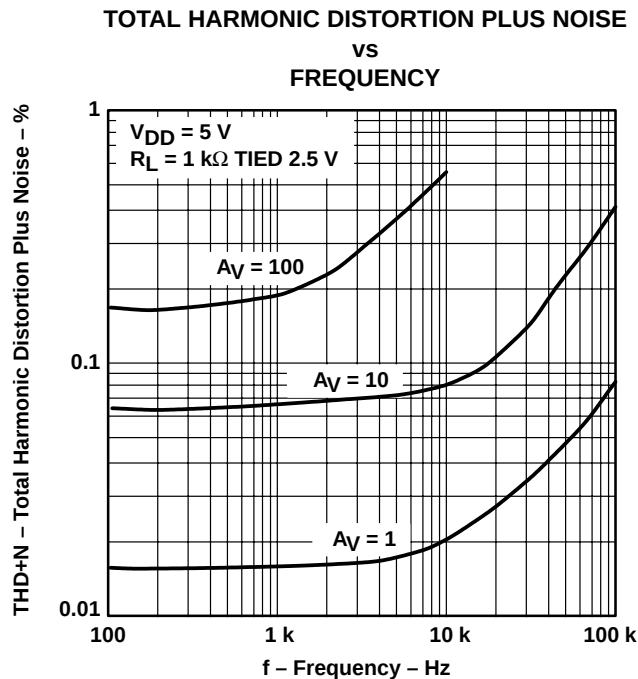


Figure 26

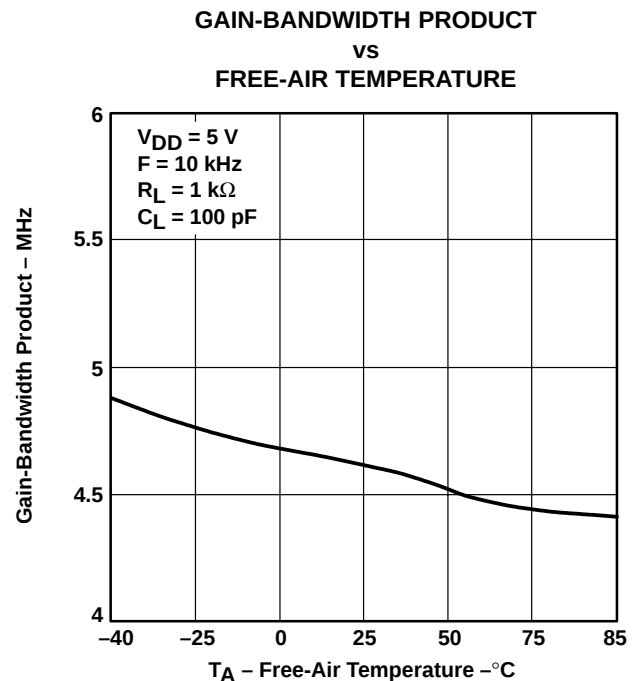
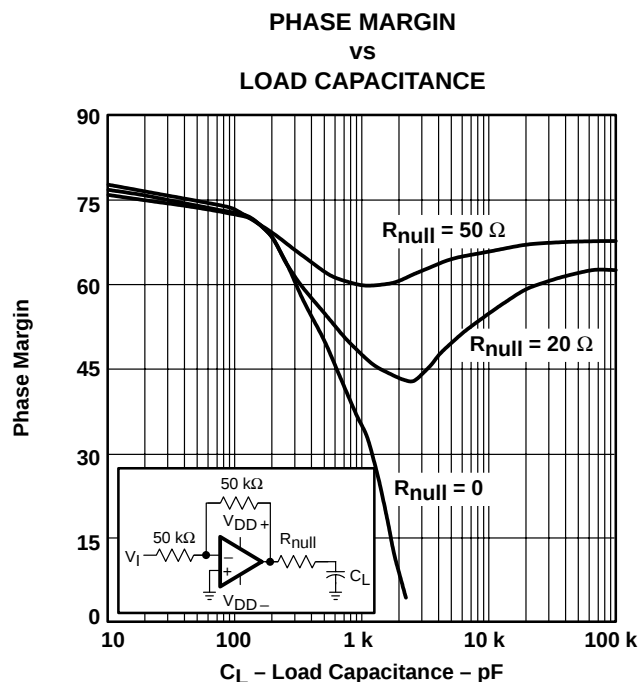


Figure 27

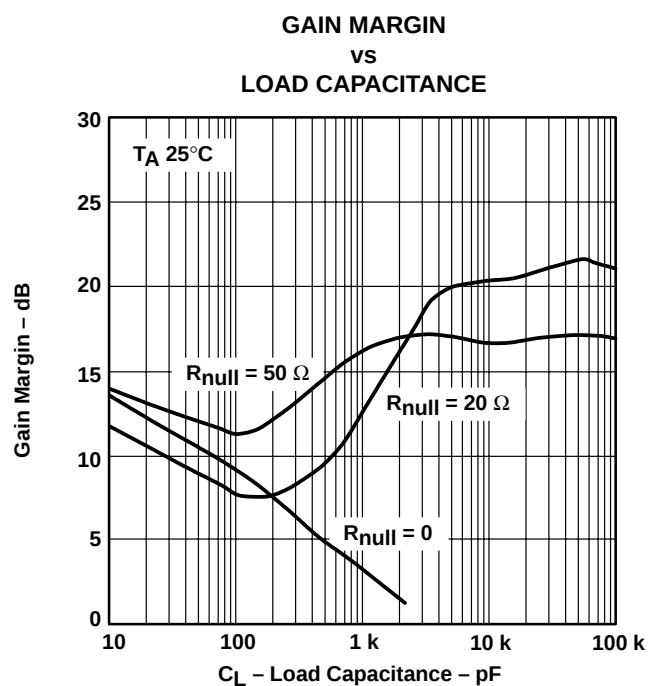
**TLC4501, TLC4501A, TLC4502, TLC4502A**  
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**PRECISION CMOS RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS**

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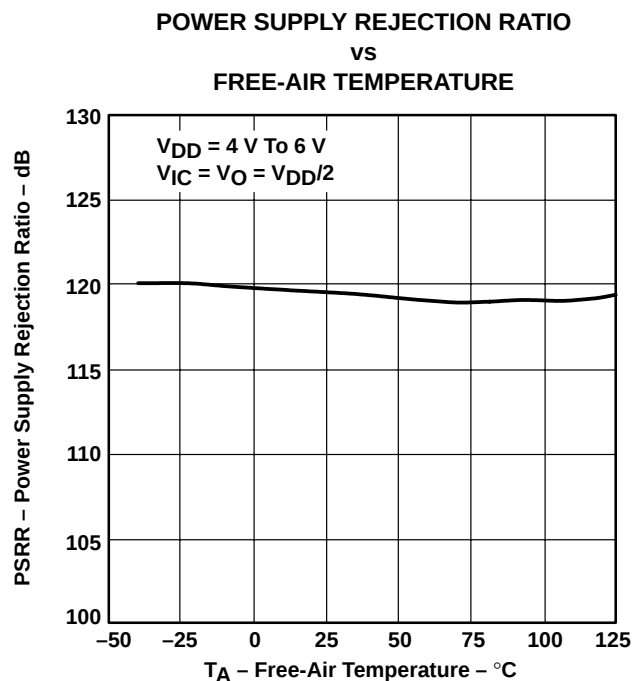
**TYPICAL CHARACTERISTICS**



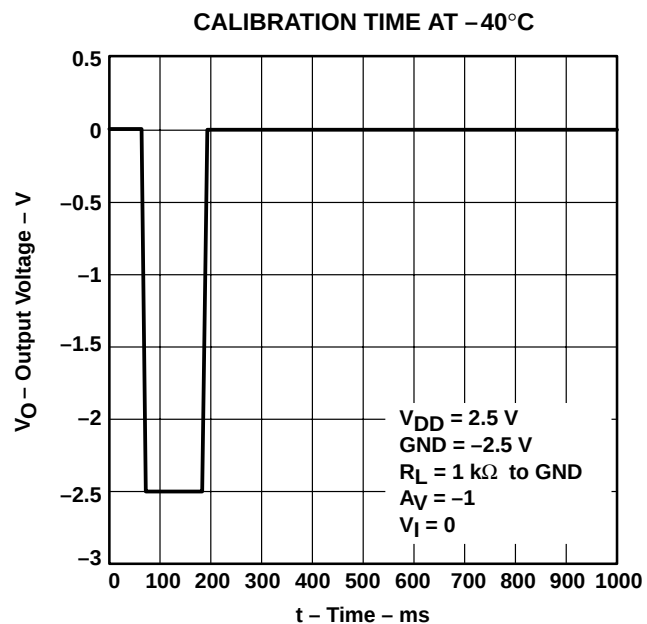
**Figure 28**



**Figure 29**



**Figure 30**



**Figure 31**

## TYPICAL CHARACTERISTICS

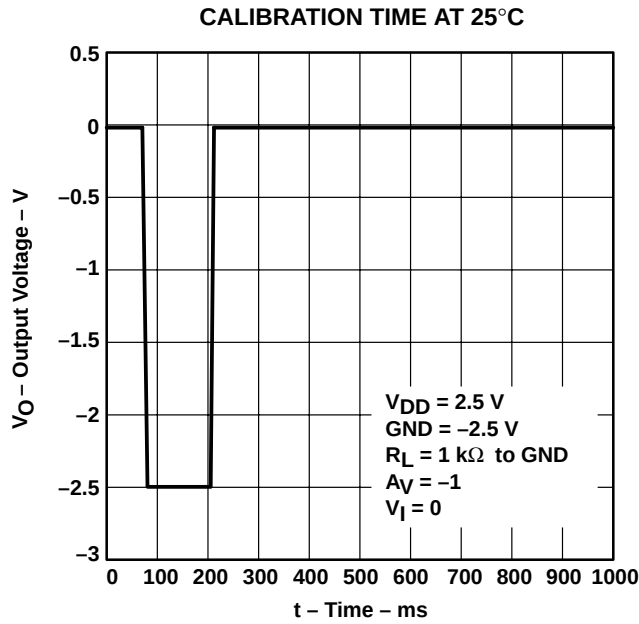


Figure 32

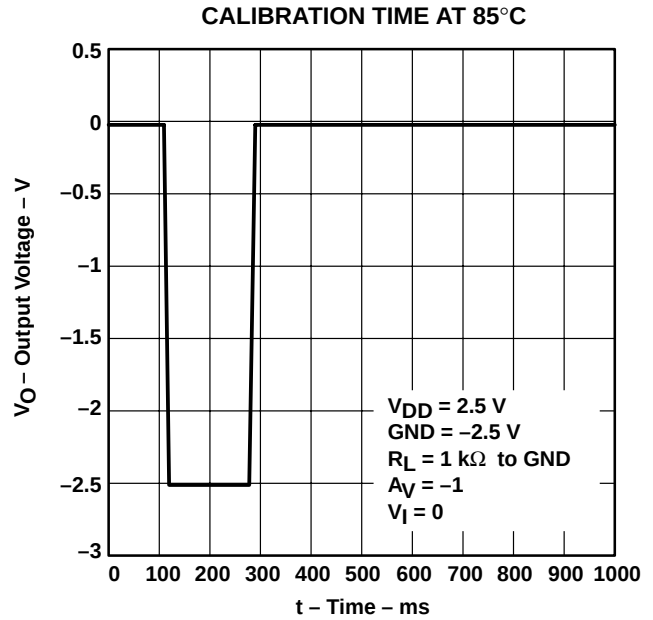


Figure 33

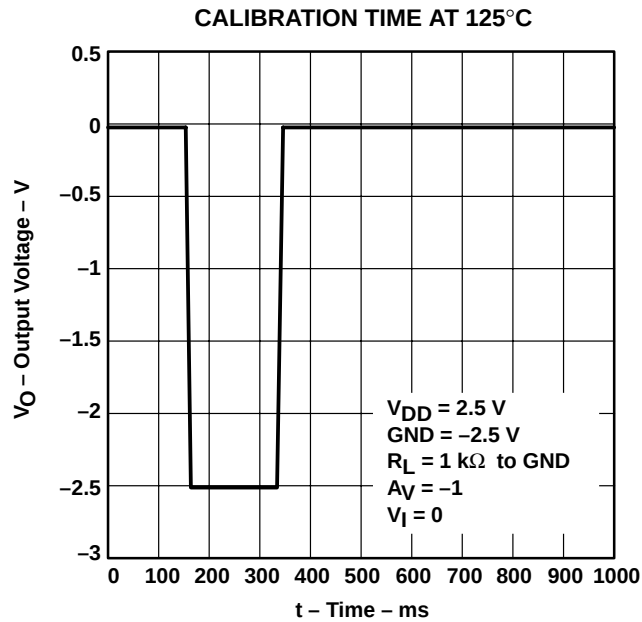


Figure 34

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

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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 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.

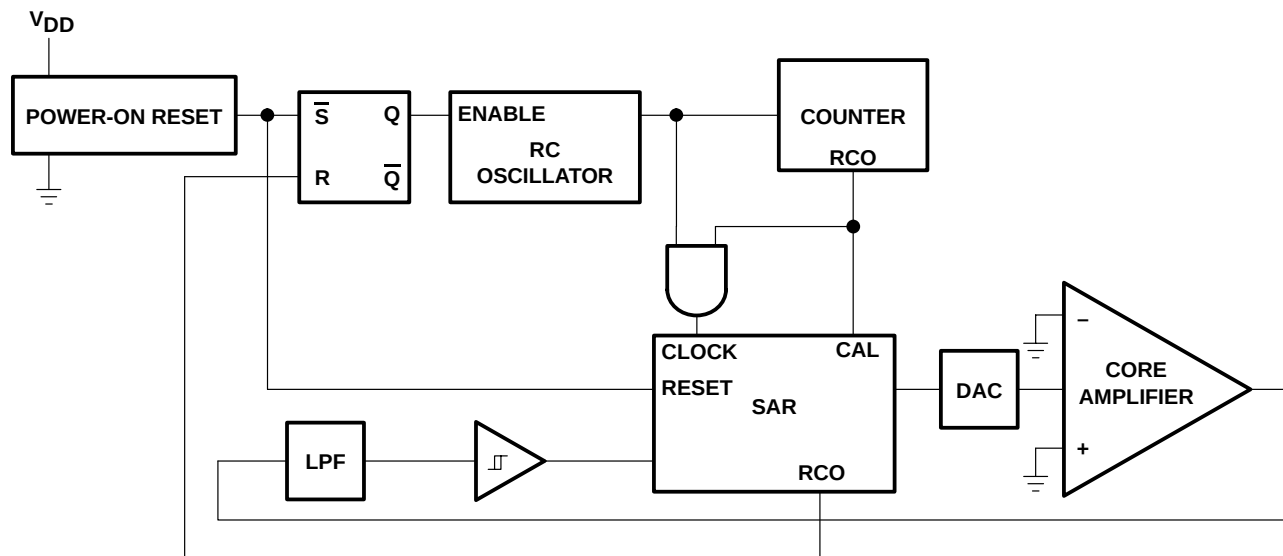
The following typical application circuits emphasize operation on only a single power supply. When complementary power supplies are available, the TLC4502 can be used in all of the standard operational amplifier circuits. In general, introducing a pseudo-ground (a bias voltage of  $V_I/2$  like that 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  $\mu$ 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

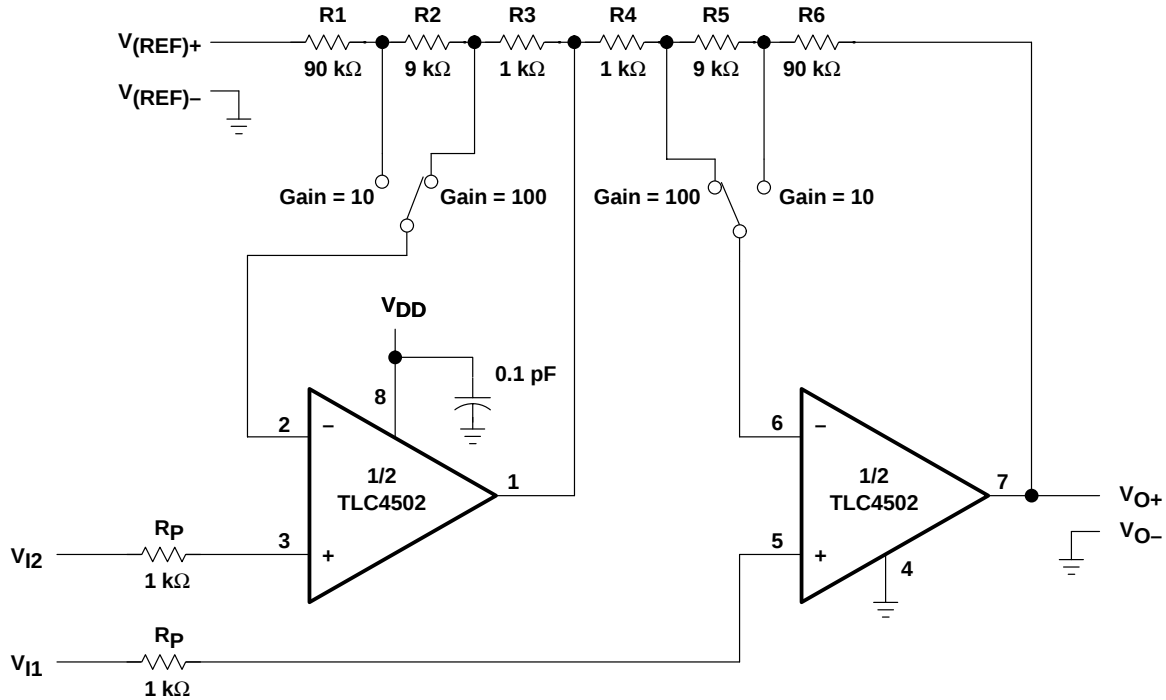
It is also ideal in circuits like:

- 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.



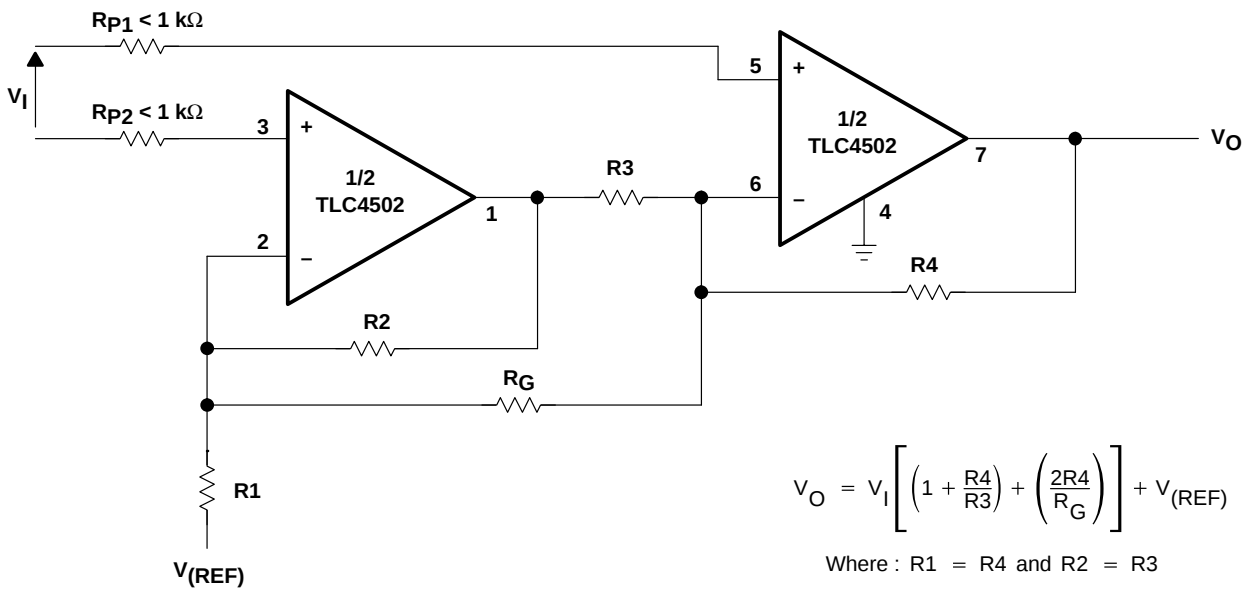
### APPLICATION INFORMATION



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

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

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



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

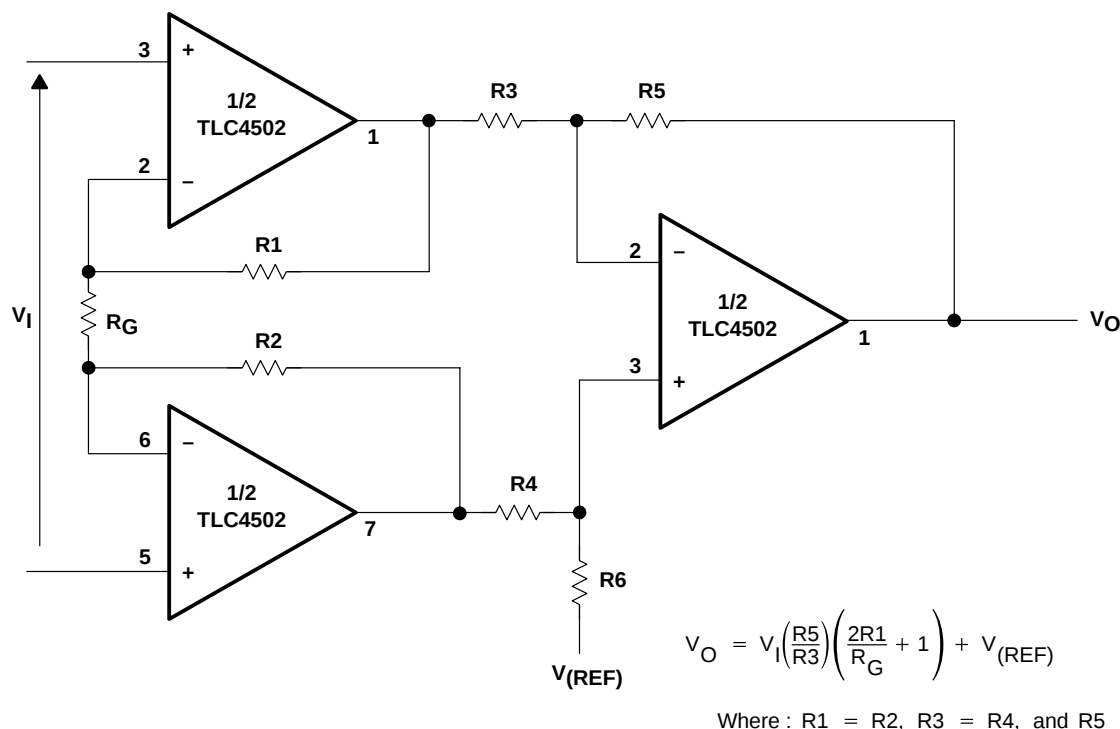
Where :  $R_1 = R_4$  and  $R_2 = R_3$

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

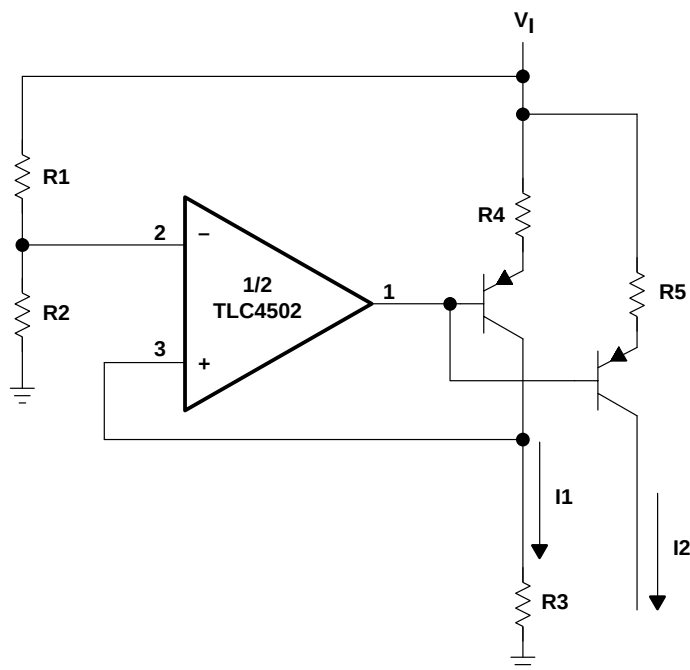
**TLC4501, TLC4501A, TLC4502, TLC4502A**  
**FAMILY OF SELF-CALIBRATING (Self-Cal™)**  
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**APPLICATION INFORMATION**



**Figure 38. Three Operational-Amplifier Instrumentation Amplifier Circuit**



**Figure 39. Fixed Current-Source Circuit**

## APPLICATION INFORMATION

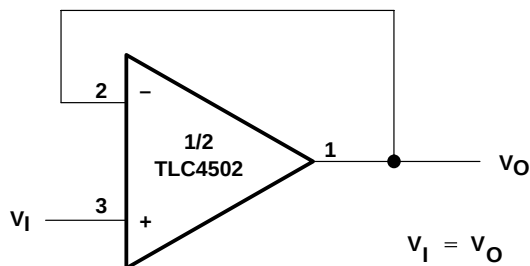


Figure 40. Voltage-Follower Circuit

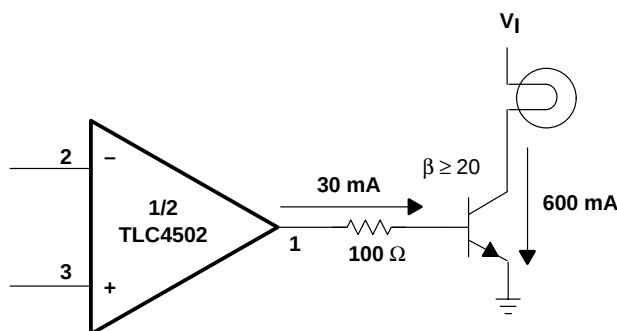


Figure 41. Lamp-Driver Circuit

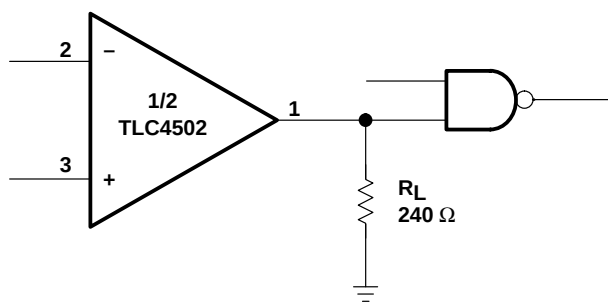
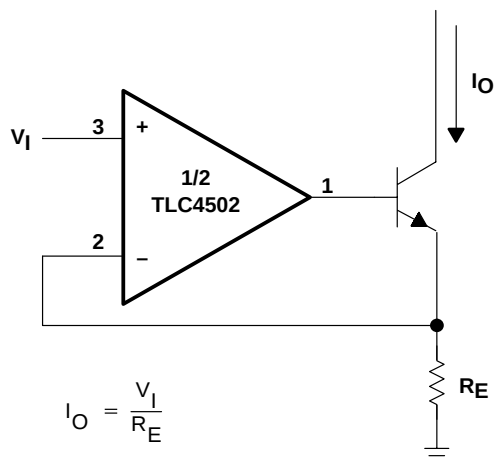


Figure 42. TTL-Driver Circuit

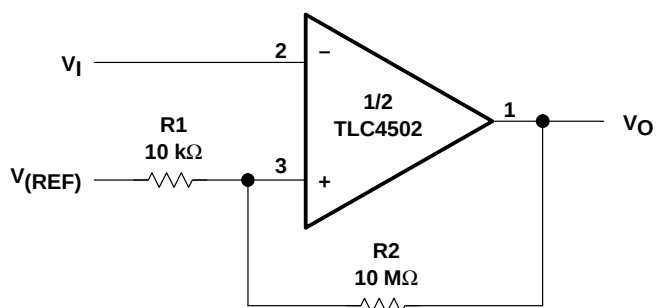
**TLC4501, TLC4501A, TLC4502, TLC4502A**  
**FAMILY OF SELF-CALIBRATING (Self-Cal™)**  
**PRECISION CMOS RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS**

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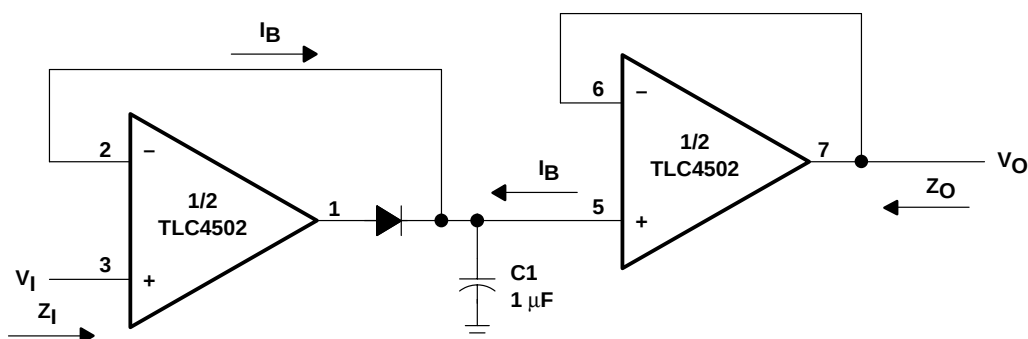
**APPLICATION INFORMATION**



**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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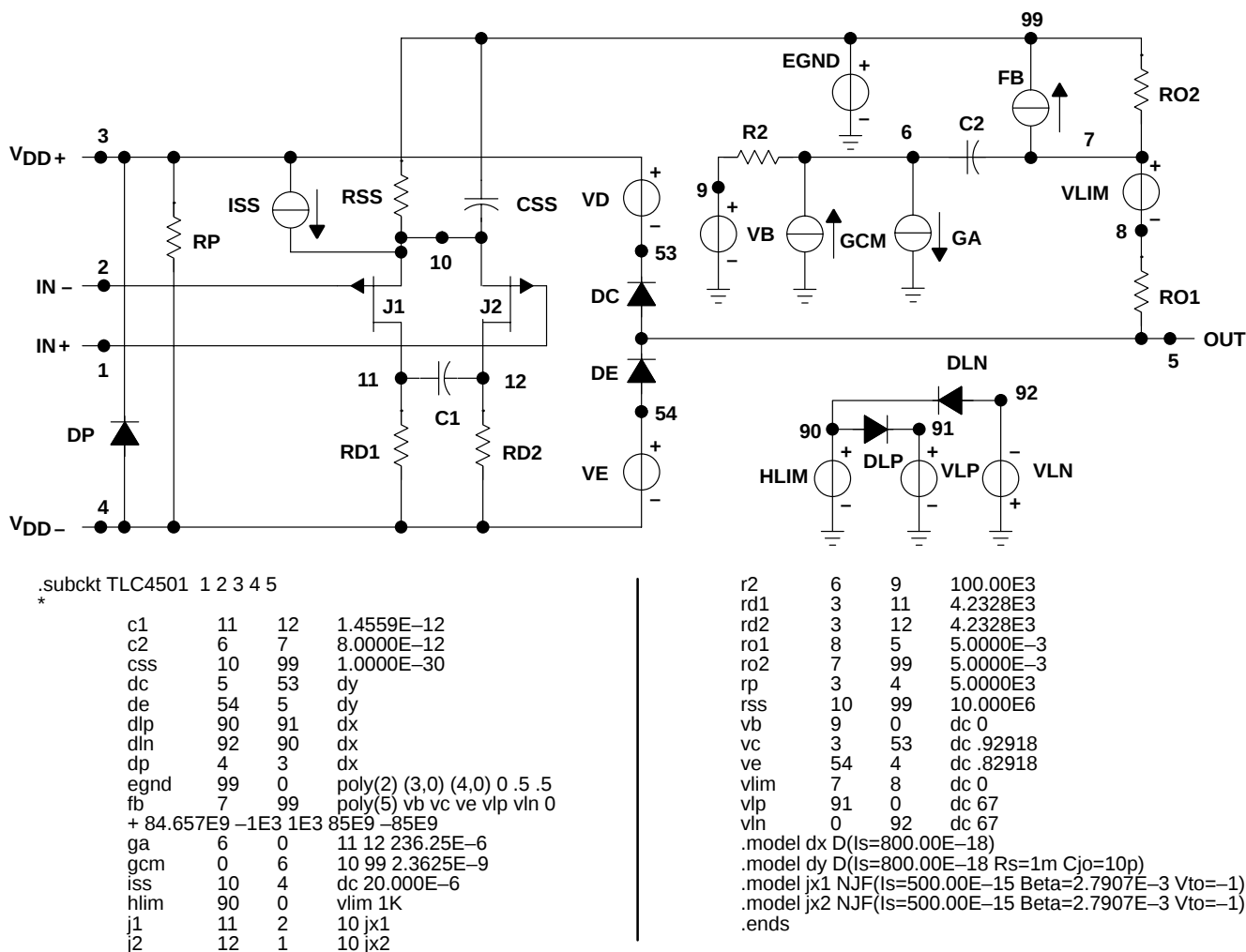
## APPLICATION INFORMATION

### 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**

*PSpice* and *Parts* are trademarks of MicroSim Corporation.



**PACKAGING INFORMATION**

| Orderable Device | Status<br>(1) | Package Type | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2)            | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|--------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| 5962-9753701QPA  | ACTIVE        | CDIP         | JG                 | 8    | 1              | TBD                        | Call TI                 | N / A for Pkg Type   | -55 to 125   | 9753701QPA<br>TLC4502M  | <a href="#">Samples</a> |
| 5962-9753702QHA  | ACTIVE        | CFP          | U                  | 10   | 1              | TBD                        | Call TI                 | N / A for Pkg Type   | -55 to 125   | 9753702QHA<br>TLC4502AM | <a href="#">Samples</a> |
| 5962-9753702QPA  | ACTIVE        | CDIP         | JG                 | 8    | 1              | TBD                        | Call TI                 | N / A for Pkg Type   | -55 to 125   | 9753702QPA<br>TLC4502AM | <a href="#">Samples</a> |
| TLC4501ACD       | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | 0 to 70      | 4501AC                  | <a href="#">Samples</a> |
| TLC4501AID       | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4501AI                  | <a href="#">Samples</a> |
| TLC4501AIDR      | ACTIVE        | SOIC         | D                  | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4501AI                  | <a href="#">Samples</a> |
| TLC4501CD        | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | 0 to 70      | 4501C                   | <a href="#">Samples</a> |
| TLC4501CDG4      | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | 0 to 70      | 4501C                   | <a href="#">Samples</a> |
| TLC4501ID        | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4501I                   | <a href="#">Samples</a> |
| TLC4501IDG4      | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4501I                   | <a href="#">Samples</a> |
| TLC4501IDR       | ACTIVE        | SOIC         | D                  | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4501I                   | <a href="#">Samples</a> |
| TLC4502ACD       | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | 0 to 70      | 4502AC                  | <a href="#">Samples</a> |
| TLC4502ACDR      | ACTIVE        | SOIC         | D                  | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | 0 to 70      | 4502AC                  | <a href="#">Samples</a> |
| TLC4502AID       | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4502AI                  | <a href="#">Samples</a> |
| TLC4502AIDR      | ACTIVE        | SOIC         | D                  | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4502AI                  | <a href="#">Samples</a> |
| TLC4502AMD       | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -55 to 125   | 4502AM                  | <a href="#">Samples</a> |
| TLC4502AMJGB     | ACTIVE        | CDIP         | JG                 | 8    | 1              | TBD                        | Call TI                 | N / A for Pkg Type   | -55 to 125   | 9753702QPA<br>TLC4502AM | <a href="#">Samples</a> |

| Orderable Device | Status<br>(1) | Package Type | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2)            | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|--------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| TLC4502AMUB      | ACTIVE        | CFP          | U                  | 10   | 1              | TBD                        | Call TI                 | N / A for Pkg Type   | -55 to 125   | 9753702QHA<br>TLC4502AM | <a href="#">Samples</a> |
| TLC4502CD        | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | 0 to 70      | 4502C                   | <a href="#">Samples</a> |
| TLC4502CDR       | ACTIVE        | SOIC         | D                  | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | 0 to 70      | 4502C                   | <a href="#">Samples</a> |
| TLC4502ID        | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4502I                   | <a href="#">Samples</a> |
| TLC4502IDR       | ACTIVE        | SOIC         | D                  | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4502I                   | <a href="#">Samples</a> |
| TLC4502IDRG4     | ACTIVE        | SOIC         | D                  | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | 4502I                   | <a href="#">Samples</a> |
| TLC4502MDG4      | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   |              | 4502M                   | <a href="#">Samples</a> |
| TLC4502MJGB      | ACTIVE        | CDIP         | JG                 | 8    | 1              | TBD                        | Call TI                 | N / A for Pkg Type   | -55 to 125   | 9753701QPA<br>TLC4502M  | <a href="#">Samples</a> |
| TLC4502QD        | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   | -40 to 125   | C4502Q                  | <a href="#">Samples</a> |
| TLC4502QDG4      | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | NIPDAU                  | Level-1-260C-UNLIM   |              | C4502Q                  | <a href="#">Samples</a> |

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBsolete:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

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

<sup>(5)</sup> 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.

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

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

**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**


\*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        |

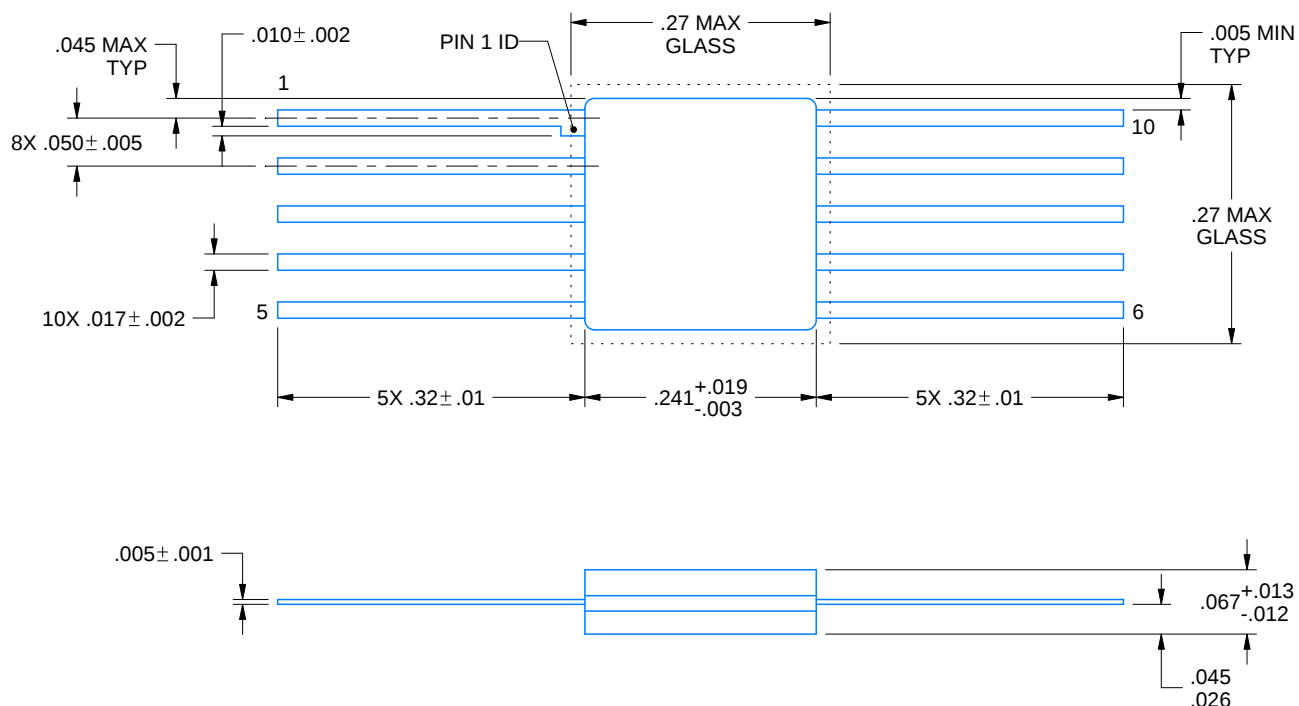
U0010A



## 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.



## PACKAGE OUTLINE

**SOIC - 1.75 mm max height**

SMALL OUTLINE INTEGRATED CIRCUIT



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.

**D0008A**

**SOIC - 1.75 mm max height**

## SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:8X



## SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

## EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



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

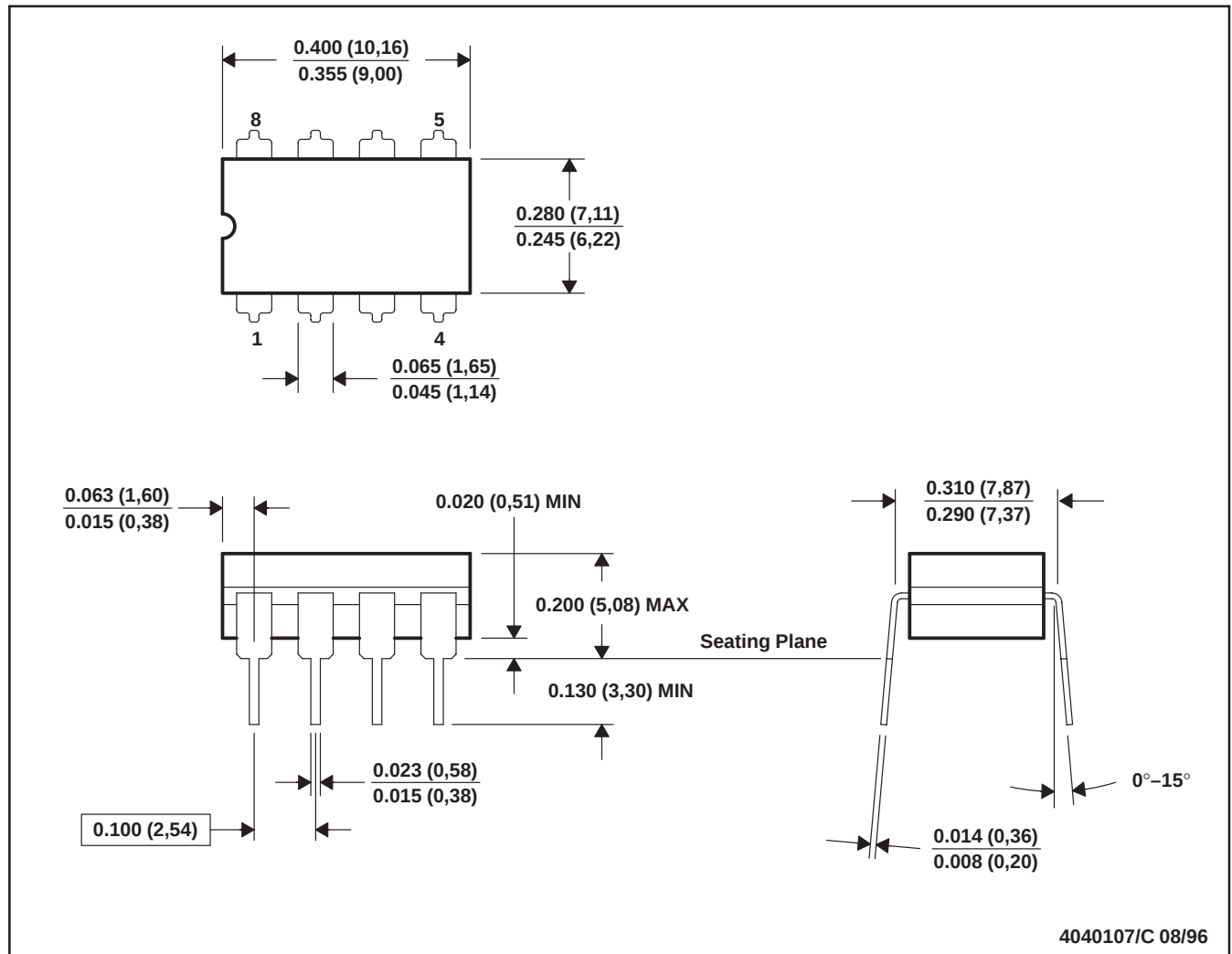
4214825/C 02/2019

NOTES: (continued)

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

## 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

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