# TLE202x-Q1, TLE202xA-Q1
# EXCALIBUR HIGH-SPEED LOW-POWER PRECISION OPERATIONAL AMPLIFIERS

SGLS199B – JANUARY 2004 – REVISED APRIL 2008

- **Qualified for Automotive Applications**
- **ESD Protection Exceeds 1000 V Per MIL-STD-883, Method 3015; Exceeds 200 V Using Machine Model (C = 200 pF, R = 0)**
- **Supply Current . . . 300 µA Max**
- **High Unity-Gain Bandwidth . . . 2 MHz Typ**
- **High Slew Rate . . . 0.45 V/µs Min**
- **Supply-Current Change Over Full Temp Range . . . 10 µA Typ at $V_{CC\pm} = \pm 15$ V**
- **Specified for Both 5-V Single-Supply and ±15-V Operation**
- **Phase-Reversal Protection**
- **High Open-Loop Gain . . . 6.5 V/µV (136 dB) Typ**
- **Low Offset Voltage . . . 100 µV Max**
- **Offset Voltage Drift With Time 0.005 µV/mo Typ**
- **Low Input Bias Current . . . 50 nA Max**
- **Low Noise Voltage . . . 19 nV/$\sqrt{\text{Hz}}$ Typ**

## description

The TLE202x and TLE202xA devices are precision, high-speed, low-power operational amplifiers using a new Texas Instruments Excalibur process. These devices combine the best features of the OP21 with highly improved slew rate and unity-gain bandwidth.

The complementary bipolar Excalibur process utilizes isolated vertical pnp transistors that yield dramatic improvement in unity-gain bandwidth and slew rate over similar devices.

The addition of a bias circuit in conjunction with this process results in extremely stable parameters with both time and temperature. This means that a precision device remains a precision device even with changes in temperature and over years of use.

This combination of excellent dc performance with a common-mode input voltage range that includes the negative rail makes these devices the ideal choice for low-level signal conditioning applications in either single-supply or split-supply configurations. In addition, these devices offer phase-reversal protection circuitry that eliminates an unexpected change in output states when one of the inputs goes below the negative supply rail.

A variety of available options includes small-outline versions for high-density systems applications.

The Q-suffix devices are characterized for operation over the full automotive temperature range of –40°C to 125°C.

## ORDERING INFORMATION†

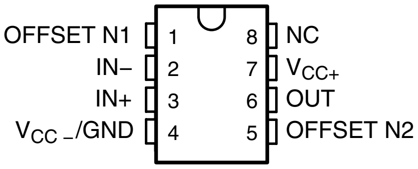
| $T_A$ | $V_{IO}$max AT 25°C | PACKAGE‡ | | ORDERABLE PART NUMBER | TOP-SIDE MARKING |
|---|---|---|---|---|---|
| –40°C to 125°C | 200 µV | SOIC (D) | Tape and reel | TLE2021AQDRQ1 | 2021AQ |
| | | TSSOP (PW) | Tape and reel | TLE2021AQPWRQ1§ | 2021AQ |
| | 500 µV | SOIC (D) | Tape and reel | TLE2021QDRQ1 | 2021Q1 |
| | | TSSOP (PW) | Tape and reel | TLE2021QPWRQ1§ | 2021Q1 |
| –40°C to 125°C | 300 µV | SOIC (D) | Tape and reel | TLE2022AQDRQ1 | 2021AQ |
| | | TSSOP (PW) | Tape and reel | TLE2022AQPWRQ1§ | 2022AQ1 |
| | 500 µV | SOIC (D) | Tape and reel | TLE2022QDRQ1 | 2022Q1 |
| | | TSSOP (PW) | Tape and reel | TLE2022QPWRQ1§ | 2022Q1 |
| –40°C to 125°C | 750 µV | SOP (DW) | Tape and reel | TLE2024AQDWRQ1 | 2024AQ1 |
| | 1000 µV | SOP (DW) | Tape and reel | TLE2024QDWRQ1 | 2024Q1 |

† For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at http://www.ti.com.

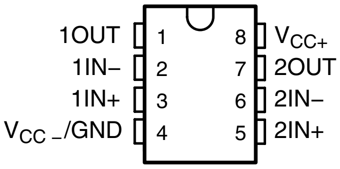
‡ Package drawings, thermal data, and symbolization are available at http://www.ti.com/packaging.

§ Product preview

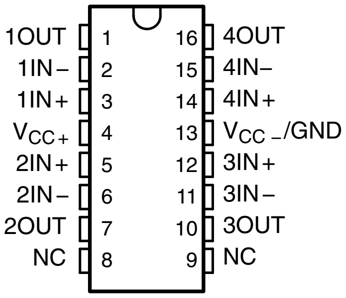
**TLE2021**
**D OR PW PACKAGE**
**(TOP VIEW)**



**TLE2022**
**D OR PW PACKAGE**
**(TOP VIEW)**

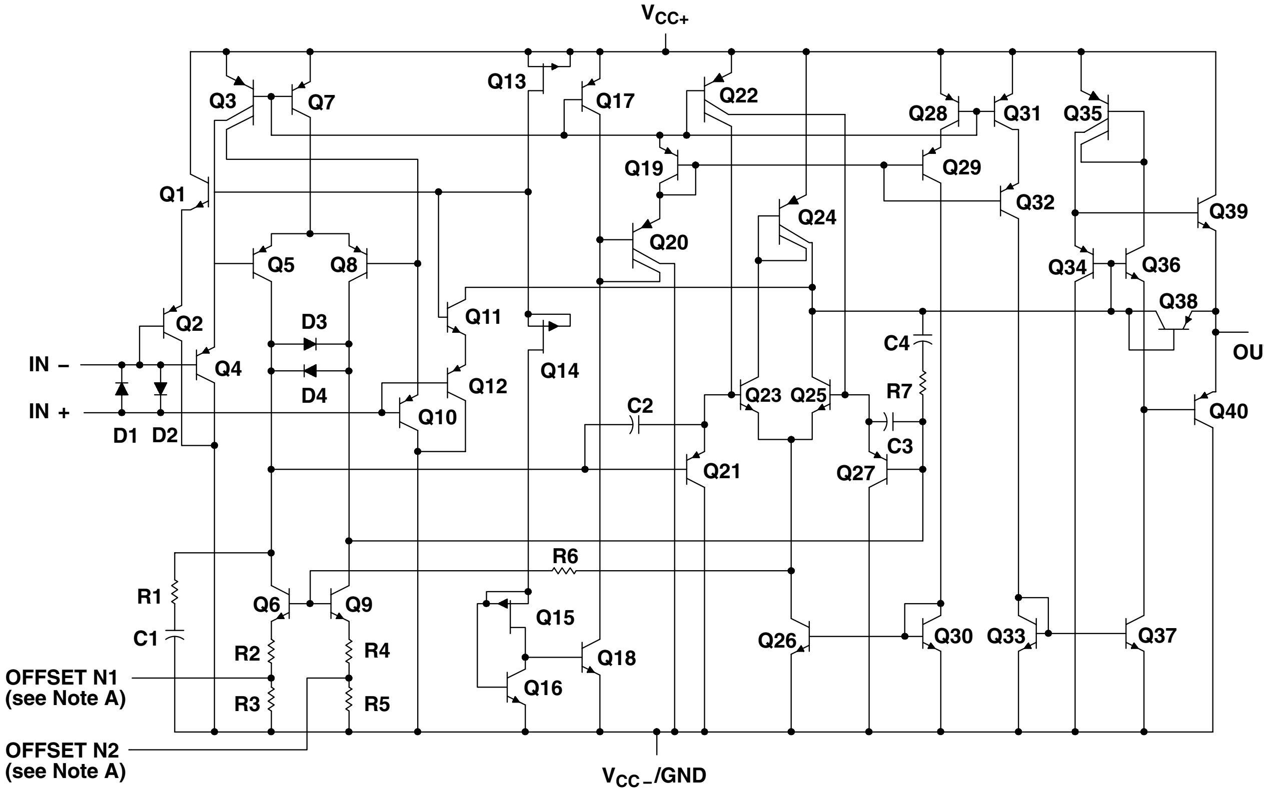


**TLE2024**
**DW PACKAGE**
**(TOP VIEW)**



NC – No internal connection

### equivalent schematic (each amplifier)



| ACTUAL DEVICE COMPONENT COUNT | | | |
|---|---|---|---|
| COMPONENT | TLE2021 | TLE2022 | TLE2024 |
| Transistors | 40 | 80 | 160 |
| Resistors | 7 | 14 | 28 |
| Diodes | 4 | 8 | 16 |
| Capacitors | 4 | 8 | 16 |

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

| | | |
|---|---|---|
| Supply voltage, $V_{CC+}$ (see Note 1) | | 20 V |
| Supply voltage, $V_{CC-}$ (see Note 1) | | –20 V |
| Differential input voltage, $V_{ID}$ (see Note 2) | | ±0.6 V |
| Input voltage range, $V_I$ (any input, see Note 1) | | $\pm V_{CC}$ |
| Input current, $I_I$ (each input) | | ±1 mA |
| Output current, $I_O$ (each output): | TLE2021 | ±20 mA |
| | TLE2022 | ±30 mA |
| | TLE2024 | ±40 mA |
| Total current into $V_{CC+}$ | | 80 mA |
| Total current out of $V_{CC-}$ | | 80 mA |
| Duration of short-circuit current at (or below) 25°C (see Note 3) | | unlimited |
| Operating free-air temperature range, $T_A$: Q suffix | | –40°C to 125°C |
| Operating virtual junction temperature, $T_J$ | | 150°C |
| Package thermal impedance, $R_{\theta JA}$ (see Notes 4 and 5): | D (8 pin) | 97°C/W |
| | DW (16 pin) | 57°C/W |
| | PW (8 pin) | 149°C/W |
| | PW (14 pin) | 113°C/W |
| Storage temperature range, $T_{stg}$ | | –65°C to 150°C |
| Lead temperature 1,6 mm (1/16 inch) from case for 3 seconds: D or PW package | | 300°C |

† Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES:
1. All voltage values, except differential voltages, are with respect to the midpoint between $V_{CC+}$, and $V_{CC-}$.
2. Differential voltages are at IN+ with respect to IN–. Excessive current flows if a differential input voltage in excess of approximately ±600 mV is applied between the inputs unless some limiting resistance is used.
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.
4. Maximum power dissipation is a function of $T_J$(max), $\theta_{JA}$, and $T_A$. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) - T_A)/\theta_{JA}$. Selecting the maximum of 150°C can affect reliability.
5. The package thermal impedance is calculated in accordance with JESD 51-7.

## recommended operating conditions

| | | MIN | MAX | UNIT |
|---|---|---|---|---|
| Supply voltage, $V_{CC}$ | | ±2 | ±20 | V |
| Common-mode input voltage, $V_{IC}$ | $V_{CC} = \pm 5$ V | 0 | 3.2 | V |
| | $V_{CC\pm} = \pm 15$ V | –15 | 13.2 | |
| Operating free-air temperature, $T_A$ | | –40 | 125 | °C |

## TLE2021 electrical characteristics at specified free-air temperature, $V_{CC}$ = 5 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $T_A$† | TLE2021-Q1 | | | TLE2021A-Q1 | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | $V_{IC}$ = 0, $R_S$ = 50 Ω | 25°C | | 120 | 600 | | 100 | 400 | µV |
| | | | Full range | | | 800 | | | 550 | |
| $\alpha_{VIO}$ | Temperature coefficient of input offset voltage | | Full range | | 2 | | | 2 | | µV/°C |
| | Input offset voltage long-term drift (see Note 4) | | 25°C | | 0.005 | | | 0.005 | | µV/mo |
| $I_{IO}$ | Input offset current | | 25°C | | 0.2 | 6 | | 0.2 | 6 | nA |
| | | | Full range | | | 10 | | | 10 | |
| $I_{IB}$ | Input bias current | | 25°C | | 25 | 70 | | 25 | 70 | nA |
| | | | Full range | | | 90 | | | 90 | |
| $V_{ICR}$ | Common-mode input voltage range | $R_S$ = 50 Ω | 25°C | 0<br>to<br>3.5 | −0.3<br>to<br>4 | | 0<br>to<br>3.5 | −0.3<br>to<br>4 | | V |
| | | | Full range | 0<br>to<br>3.2 | | | 0<br>to<br>3.2 | | | |
| $V_{OH}$ | High-level output voltage | $R_L$ = 10 kΩ | 25°C | 4 | 4.3 | | 4 | 4.3 | | V |
| | | | Full range | 3.8 | | | 3.8 | | | |
| $V_{OL}$ | Low-level output voltage | | 25°C | | 0.7 | 0.8 | | 0.7 | 0.8 | V |
| | | | Full range | | | 0.95 | | | 0.95 | |
| $A_{VD}$ | Large-signal differential voltage amplification | $V_O$ = 1.4 V to 4 V, $R_L$ = 10 kΩ | 25°C | 0.3 | 1.5 | | 0.3 | 1.5 | | V/µV |
| | | | Full range | 0.1 | | | 0.1 | | | |
| CMRR | Common-mode rejection ratio | $V_{IC}$ = $V_{ICR}$min, $R_S$ = 50 Ω | 25°C | 85 | 110 | | 85 | 110 | | dB |
| | | | Full range | 80 | | | 80 | | | |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$) | $V_{CC}$ = 5 V to 30 V | 25°C | 105 | 120 | | 105 | 120 | | dB |
| | | | Full range | 100 | | | 100 | | | |
| $I_{CC}$ | Supply current | $V_O$ = 2.5 V, No load | 25°C | | 170 | 300 | | 170 | 300 | µA |
| | | | Full range | | | 300 | | | 300 | |
| $\Delta I_{CC}$ | Supply current change over operating temperature range | | Full range | | 9 | | | 9 | | µA |

† Full range is –40°C to 125°C.

NOTE 4: Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A$ = 150°C extrapolated to $T_A$ = 25°C using the Arrhenius equation and assuming an activation energy of 0.96 eV.

## TLE2021 electrical characteristics at specified free-air temperature, $V_{CC} = \pm 15$ V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $T_A$† | TLE2021-Q1 | | | TLE2021A-Q1 | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | $V_{IC}$ = 0, $R_S$ = 50 Ω | 25°C | | 120 | 500 | | 80 | 300 | µV |
| | | | Full range | | | 700 | | | 450 | |
| $\alpha_{VIO}$ | Temperature coefficient of input offset voltage | | Full range | | 2 | | | 2 | | µV/°C |
| | Input offset voltage long-term drift (see Note 4) | | 25°C | | 0.006 | | | 0.006 | | µV/mo |
| $I_{IO}$ | Input offset current | | 25°C | | 0.2 | 6 | | 0.2 | 6 | nA |
| | | | Full range | | | 10 | | | 10 | |
| $I_{IB}$ | Input bias current | | 25°C | | 25 | 70 | | 25 | 70 | nA |
| | | | Full range | | | 90 | | | 90 | |
| $V_{ICR}$ | Common-mode input voltage range | $R_S$ = 50 Ω | 25°C | −15 to 13.5 | −15.3 to 14 | | −15 to 13.5 | −15.3 to 14 | | V |
| | | | Full range | −15 to 13.2 | | | −15 to 13.2 | | | |
| $V_{OM+}$ | Maximum positive peak output voltage swing | $R_L$ = 10 kΩ | 25°C | 14 | 14.3 | | 14 | 14.3 | | V |
| | | | Full range | 13.8 | | | 13.8 | | | |
| $V_{OM-}$ | Maximum negative peak output voltage swing | | 25°C | −13.7 | −14.1 | | −13.7 | −14.1 | | V |
| | | | Full range | −13.6 | | | −13.6 | | | |
| $A_{VD}$ | Large-signal differential voltage amplification | $V_O = \pm 10$ V, $R_L$ = 10 kΩ | 25°C | 1 | 6.5 | | 1 | 6.5 | | V/µV |
| | | | Full range | 0.5 | | | 0.5 | | | |
| CMRR | Common-mode rejection ratio | $V_{IC} = V_{ICR}$min, $R_S$ = 50 Ω | 25°C | 100 | 115 | | 100 | 115 | | dB |
| | | | Full range | 96 | | | 96 | | | |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$) | $V_{CC\pm} = \pm 2.5$ V to $\pm 15$ V | 25°C | 105 | 120 | | 105 | 120 | | dB |
| | | | Full range | 100 | | | 100 | | | |
| $I_{CC}$ | Supply current | $V_O$ = 0, No load | 25°C | | 200 | 350 | | 200 | 350 | µA |
| | | | Full range | | | 350 | | | 350 | |
| $\Delta I_{CC}$ | Supply current change over operating temperature range | | Full range | | 10 | | | 10 | | µA |

† Full range is −40°C to 125°C.

NOTE 4: Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A$ = 150°C extrapolated to $T_A$ = 25°C using the Arrhenius equation and assuming an activation energy of 0.96 eV.

## TLE2022 electrical characteristics at specified free-air temperature, $V_{CC}$ = 5 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $T_A$† | TLE2022-Q1 | | | TLE2022A-Q1 | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | $V_{IC}$ = 0, $R_S$ = 50 Ω | 25°C | | | 600 | | | 400 | μV |
| | | | Full range | | | 800 | | | 550 | |
| $\alpha_{VIO}$ | Temperature coefficient of input offset voltage | | Full range | | 2 | | | 2 | | μV/°C |
| | Input offset voltage long-term drift (see Note 4) | | 25°C | | 0.005 | | | 0.005 | | μV/mo |
| $I_{IO}$ | Input offset current | | 25°C | | 0.5 | 6 | | 0.4 | 6 | nA |
| | | | Full range | | | 10 | | | 10 | |
| $I_{IB}$ | Input bias current | | 25°C | | 35 | 70 | | 33 | 70 | nA |
| | | | Full range | | | 90 | | | 90 | |
| $V_{ICR}$ | Common-mode input voltage range | $R_S$ = 50 Ω | 25°C | 0 to 3.5 | –0.3 to 4 | | 0 to 3.5 | –0.3 to 4 | | V |
| | | | Full range | 0 to 3.2 | | | 0 to 3.2 | | | |
| $V_{OH}$ | High-level output voltage | $R_L$ = 10 kΩ | 25°C | 4 | 4.3 | | 4 | 4.3 | | V |
| | | | Full range | 3.8 | | | 3.8 | | | |
| $V_{OL}$ | Low-level output voltage | | 25°C | | 0.7 | 0.8 | | 0.7 | 0.8 | V |
| | | | Full range | | | 0.95 | | | 0.95 | |
| $A_{VD}$ | Large-signal differential voltage amplification | $V_O$ = 1.4 V to 4 V, $R_L$ = 10 kΩ | 25°C | 0.3 | 1.5 | | 0.4 | 1.5 | | V/μV |
| | | | Full range | 0.1 | | | 0.1 | | | |
| CMRR | Common-mode rejection ratio | $V_{IC}$ = $V_{ICR}$min, $R_S$ = 50 Ω | 25°C | 85 | 100 | | 87 | 102 | | dB |
| | | | Full range | 80 | | | 82 | | | |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$) | $V_{CC}$ = 5 V to 30 V | 25°C | 100 | 115 | | 103 | 118 | | dB |
| | | | Full range | 95 | | | 98 | | | |
| $I_{CC}$ | Supply current | $V_O$ = 2.5 V, No load | 25°C | | 450 | 600 | | 450 | 600 | μA |
| | | | Full range | | | 600 | | | 600 | |
| $\Delta I_{CC}$ | Supply current change over operating temperature range | | Full range | | 37 | | | 37 | | μA |

† Full range is –40°C to 125°C.

NOTE 4: Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A$ = 150°C extrapolated to $T_A$ = 25°C using the Arrhenius equation and assuming an activation energy of 0.96 eV.

## TLE2022 electrical characteristics at specified free-air temperature, $V_{CC}$ = ±15 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $T_A$† | TLE2022-Q1 | | | TLE2022A-Q1 | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | $V_{IC}$ = 0, $R_S$ = 50 Ω | 25°C | | 150 | 500 | | 120 | 300 | µV |
| | | | Full range | | | 700 | | | 450 | |
| $\alpha_{VIO}$ | Temperature coefficient of input offset voltage | | Full range | | 2 | | | 2 | | µV/°C |
| | Input offset voltage long-term drift (see Note 4) | | 25°C | | 0.006 | | | 0.006 | | µV/mo |
| $I_{IO}$ | Input offset current | | 25°C | | 0.5 | 6 | | 0.4 | 6 | nA |
| | | | Full range | | | 10 | | | 10 | |
| $I_{IB}$ | Input bias current | | 25°C | | 35 | 70 | | 33 | 70 | nA |
| | | | Full range | | | 90 | | | 90 | |
| $V_{ICR}$ | Common-mode input voltage range | $R_S$ = 50 Ω | 25°C | −15 to 13.5 | −15.3 to 14 | | −15 to 13.5 | −15.3 to 14 | | V |
| | | | Full range | −15 to 13.2 | | | −15 to 13.2 | | | |
| $V_{OM+}$ | Maximum positive peak output voltage swing | $R_L$ = 10 kΩ | 25°C | 14 | 14.3 | | 14 | 14.3 | | V |
| | | | Full range | 13.8 | | | 13.8 | | | |
| $V_{OM-}$ | Maximum negative peak output voltage swing | | 25°C | −13.7 | −14.1 | | −13.7 | −14.1 | | V |
| | | | Full range | −13.6 | | | −13.6 | | | |
| $A_{VD}$ | Large-signal differential voltage amplification | $V_O$ = ±10 V, $R_L$ = 10 kΩ | 25°C | 0.8 | 4 | | 1 | 7 | | V/µV |
| | | | Full range | 0.8 | | | 1 | | | |
| CMRR | Common-mode rejection ratio | $V_{IC}$ = $V_{ICR}$min, $R_S$ = 50 Ω | 25°C | 95 | 106 | | 97 | 109 | | dB |
| | | | Full range | 91 | | | 93 | | | |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$) | $V_{CC\pm}$ = ±2.5 V to ±15 V | 25°C | 100 | 115 | | 103 | 118 | | dB |
| | | | Full range | 95 | | | 98 | | | |
| $I_{CC}$ | Supply current | $V_O$ = 0, No load | 25°C | | 550 | 700 | | 550 | 700 | µA |
| | | | Full range | | | 700 | | | 700 | |
| $\Delta I_{CC}$ | Supply current change over operating temperature range | | Full range | | 60 | | | 60 | | µA |

† Full range is –40°C to 125°C.

NOTE 4: Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A$ = 150°C extrapolated to $T_A$ = 25°C using the Arrhenius equation and assuming an activation energy of 0.96 eV.

## TLE2024 electrical characteristics at specified free-air temperature, $V_{CC}$ = 5 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $T_A$† | TLE2024-Q1 | | | TLE2024A-Q1 | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | $V_{IC}$ = 0, $R_S$ = 50 Ω | 25°C | | | 1100 | | | 850 | µV |
| | | | Full range | | | 1300 | | | 1050 | |
| $\alpha_{VIO}$ | Temperature coefficient of input offset voltage | | Full range | | 2 | | | 2 | | µV/°C |
| | Input offset voltage long-term drift (see Note 4) | | 25°C | | 0.005 | | | 0.005 | | µV/mo |
| $I_{IO}$ | Input offset current | | 25°C | | 0.6 | 6 | | 0.5 | 6 | nA |
| | | | Full range | | | 10 | | | 10 | |
| $I_{IB}$ | Input bias current | | 25°C | | 45 | 70 | | 40 | 70 | nA |
| | | | Full range | | | 90 | | | 90 | |
| $V_{ICR}$ | Common-mode input voltage range | $R_S$ = 50 Ω | 25°C | 0<br>to<br>3.5 | −0.3<br>to<br>4 | | 0<br>to<br>3.5 | −0.3<br>to<br>4 | | V |
| | | | Full range | 0<br>to<br>3.2 | | | 0<br>to<br>3.2 | | | |
| $V_{OH}$ | High-level output voltage | $R_L$ = 10 kΩ | 25°C | 3.9 | 4.2 | | 3.9 | 4.2 | | V |
| | | | Full range | 3.7 | | | 3.7 | | | |
| $V_{OL}$ | Low-level output voltage | | 25°C | | 0.7 | 0.8 | | 0.7 | 0.8 | V |
| | | | Full range | | | 0.95 | | | 0.95 | |
| $A_{VD}$ | Large-signal differential voltage amplification | $V_O$ = 1.4 V to 4 V, $R_L$ = 10 kΩ | 25°C | 0.2 | 1.5 | | 0.3 | 1.5 | | V/µV |
| | | | Full range | 0.1 | | | 0.1 | | | |
| CMRR | Common-mode rejection ratio | $V_{IC} = V_{ICR}\text{min}$, $R_S$ = 50 Ω | 25°C | 80 | 90 | | 82 | 92 | | dB |
| | | | Full range | 80 | | | 82 | | | |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$) | $V_{CC\pm}$ = ±2.5 V to ±15 V | 25°C | 98 | 112 | | 100 | 115 | | dB |
| | | | Full range | 93 | | | 95 | | | |
| $I_{CC}$ | Supply current | $V_O$ = 0, No load | 25°C | | 800 | 1200 | | 800 | 1200 | µA |
| | | | Full range | | | 1200 | | | 1200 | |
| $\Delta I_{CC}$ | Supply current change over operating temperature range | | Full range | | 50 | | | 50 | | µA |

† Full range is –40°C to 125°C.

NOTE 4: Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A$ = 150°C extrapolated to $T_A$ = 25°C using the Arrhenius equation and assuming an activation energy of 0.96 eV.

## TLE2024 electrical characteristics at specified free-air temperature, $V_{CC}$ = ±15 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $T_A$† | TLE2024-Q1 | | | TLE2024A-Q1 | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | $V_{IC}$ = 0, $R_S$ = 50 Ω | 25°C | | | 1000 | | | 750 | μV |
| | | | Full range | | | 1200 | | | 950 | |
| $\alpha_{VIO}$ | Temperature coefficient of input offset voltage | | Full range | | 2 | | | 2 | | μV/°C |
| | Input offset voltage long-term drift (see Note 4) | | 25°C | | 0.006 | | | 0.006 | | μV/mo |
| $I_{IO}$ | Input offset current | | 25°C | | 0.6 | 6 | | 0.2 | 6 | nA |
| | | | Full range | | | 10 | | | 10 | |
| $I_{IB}$ | Input bias current | | 25°C | | 50 | 70 | | 45 | 70 | nA |
| | | | Full range | | | 90 | | | 90 | |
| $V_{ICR}$ | Common-mode input voltage range | $R_S$ = 50 Ω | 25°C | −15 to 13.5 | −15.3 to 14 | | −15 to 13.5 | −15.3 to 14 | | V |
| | | | Full range | −15 to 13.2 | | | −15 to 13.2 | | | |
| $V_{OM+}$ | Maximum positive peak output voltage swing | $R_L$ = 10 kΩ | 25°C | 13.8 | 14.1 | | 13.8 | 14.2 | | V |
| | | | Full range | 13.7 | | | 13.7 | | | |
| $V_{OM-}$ | Maximum negative peak output voltage swing | | 25°C | −13.7 | −14.1 | | −13.7 | −14.1 | | V |
| | | | Full range | −13.6 | | | −13.6 | | | |
| $A_{VD}$ | Large-signal differential voltage amplification | $V_O$ = ±10 V, $R_L$ = 10 kΩ | 25°C | 0.4 | 2 | | 0.8 | 4 | | V/μV |
| | | | Full range | 0.4 | | | 0.8 | | | |
| CMRR | Common-mode rejection ratio | $V_{IC} = V_{ICR}$min, $R_S$ = 50 Ω | 25°C | 92 | 102 | | 94 | 105 | | dB |
| | | | Full range | 88 | | | 90 | | | |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$) | $V_{CC\pm}$ = ±2.5 V to ±15 V | 25°C | 98 | 112 | | 100 | 115 | | dB |
| | | | Full range | 93 | | | 95 | | | |
| $I_{CC}$ | Supply current | $V_O$ = 0, No load | 25°C | | 1050 | 1400 | | 1050 | 1400 | μA |
| | | | Full range | | | 1400 | | | 1400 | |
| $\Delta I_{CC}$ | Supply current change over operating temperature range | | Full range | | 85 | | | 85 | | μA |

† Full range is –40°C to 125°C.

NOTE 4: Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A$ = 150°C extrapolated to $T_A$ = 25°C using the Arrhenius equation and assuming an activation energy of 0.96 eV.

## TLE2021 operating characteristics, $V_{CC}$ = 5 V, $T_A$ = 25°C

| PARAMETER | | TEST CONDITIONS | $T_A$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| SR | Slew rate at unity gain | $V_O$ = 1 V to 3 V, See Figure 1 | 25°C | | 0.5 | | V/μs |
| $V_n$ | Equivalent input noise voltage (see Figure 2) | f = 10 Hz | 25°C | | 21 | | nV/Hz |
| | | f = 1 kHz | 25°C | | 17 | | |
| $V_{N(PP)}$ | Peak-to-peak equivalent input noise voltage | f = 0.1 to 1 Hz | 25°C | | 0.16 | | μV |
| | | f = 0.1 to 10 Hz | 25°C | | 0.47 | | |
| $I_n$ | Equivalent input noise current | | 25°C | | 0.9 | | pA/Hz |
| $B_1$ | Unity-gain bandwidth | See Figure 3 | 25°C | | 1.2 | | MHz |
| $\phi_m$ | Phase margin at unity gain | See Figure 3 | 25°C | | 42° | | |

## TLE2021 operating characteristics at specified free-air temperature, $V_{CC}$ = ±15 V

| PARAMETER | | TEST CONDITIONS | $T_A$† | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| SR | Slew rate at unity gain | $V_O$ = ±10 V, See Figure 1 | 25°C | 0.45 | 0.65 | | V/μs |
| | | | Full range | 0.4 | | | |
| $V_n$ | Equivalent input noise voltage (see Figure 2) | f = 10 Hz | 25°C | | 19 | | nV/Hz |
| | | f = 1 kHz | 25°C | | 15 | | |
| $V_{N(PP)}$ | Peak-to-peak equivalent input noise voltage | f = 0.1 to 1 Hz | 25°C | | 0.16 | | μV |
| | | f = 0.1 to 10 Hz | 25°C | | 0.47 | | |
| $I_n$ | Equivalent input noise current | | 25°C | | 0.09 | | pA/Hz |
| $B_1$ | Unity-gain bandwidth | See Figure 3 | 25°C | | 2 | | MHz |
| $\phi_m$ | Phase margin at unity gain | See Figure 3 | 25°C | | 46° | | |

† Full range is –40°C to 125°C for the Q-suffix devices.

## TLE2022 operating characteristics, $V_{CC}$ = 5 V, $T_A$ = 25°C

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| SR | Slew rate at unity gain | $V_O$ = 1 V to 3 V, See Figure 1 | | 0.5 | | V/μs |
| $V_n$ | Equivalent input noise voltage (see Figure 2) | f = 10 Hz | | 21 | | $nV/\sqrt{Hz}$ |
| | | f = 1 kHz | | 17 | | |
| $V_{N(PP)}$ | Peak-to-peak equivalent input noise voltage | f = 0.1 to 1 Hz | | 0.16 | | μV |
| | | f = 0.1 to 10 Hz | | 0.47 | | |
| $I_n$ | Equivalent input noise current | | | 0.1 | | $pA/\sqrt{Hz}$ |
| $B_1$ | Unity-gain bandwidth | See Figure 3 | | 1.7 | | MHz |
| $\phi_m$ | Phase margin at unity gain | See Figure 3 | | 47° | | |

## TLE2022 operating characteristics at specified free-air temperature, $V_{CC}$ = ±15 V

| PARAMETER | | TEST CONDITIONS | $T_A$† | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| SR | Slew rate at unity gain | $V_O$ = ±10 V, See Figure 1 | 25°C | 0.45 | 0.65 | | V/µs |
| | | | Full range | 0.4 | | | |
| $V_n$ | Equivalent input noise voltage (see Figure 2) | f = 10 Hz | 25°C | | 19 | | nV/√Hz |
| | | f = 1 kHz | 25°C | | 15 | | |
| $V_{N(PP)}$ | Peak-to-peak equivalent input noise voltage | f = 0.1 to 1 Hz | 25°C | | 0.16 | | µV |
| | | f = 0.1 to 10 Hz | 25°C | | 0.47 | | |
| $I_n$ | Equivalent input noise current | | 25°C | | 0.1 | | pA/√Hz |
| $B_1$ | Unity-gain bandwidth | See Figure 3 | 25°C | | 2.8 | | MHz |
| $\phi_m$ | Phase margin at unity gain | See Figure 3 | 25°C | | 52° | | |

† Full range is –40°C to 125°C.

## TLE2024 operating characteristics, $V_{CC}$ = 5 V, $T_A$ = 25°C

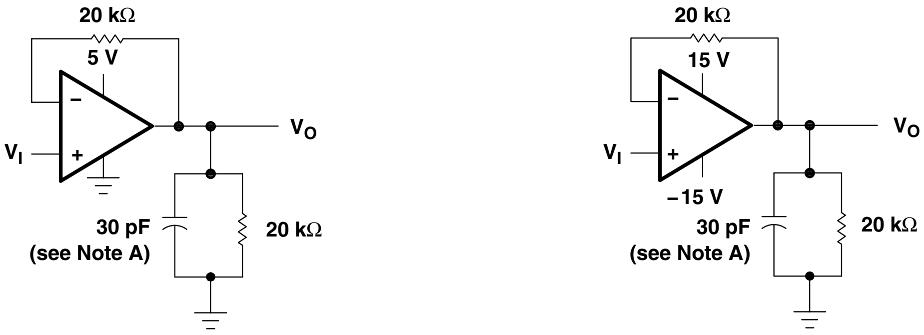
| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| SR | Slew rate at unity gain | $V_O$ = 1 V to 3 V, See Figure 1 | | 0.5 | | V/µs |
| $V_n$ | Equivalent input noise voltage (see Figure 2) | f = 10 Hz | | 21 | | nV/√Hz |
| | | f = 1 kHz | | 17 | | |
| $V_{N(PP)}$ | Peak-to-peak equivalent input noise voltage | f = 0.1 to 1 Hz | | 0.16 | | µV |
| | | f = 0.1 to 10 Hz | | 0.47 | | |
| $I_n$ | Equivalent input noise current | | | 0.1 | | pA/√Hz |
| $B_1$ | Unity-gain bandwidth | See Figure 3 | | 1.7 | | MHz |
| $\phi_m$ | Phase margin at unity gain | See Figure 3 | | 47° | | |

## TLE2024 operating characteristics at specified free-air temperature, $V_{CC}$ = ±15 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $T_A$† | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| SR | Slew rate at unity gain | $V_O$ = ±10 V, See Figure 1 | 25°C | 0.45 | 0.7 | | V/µs |
| | | | Full range | 0.4 | | | |
| $V_n$ | Equivalent input noise voltage (see Figure 2) | f = 10 Hz | 25°C | | 19 | | nV/√Hz |
| | | f = 1 kHz | 25°C | | 15 | | |
| $V_{N(PP)}$ | Peak-to-peak equivalent input noise voltage | f = 0.1 to 1 Hz | 25°C | | 0.16 | | µV |
| | | f = 0.1 to 10 Hz | 25°C | | 0.47 | | |
| $I_n$ | Equivalent input noise current | | 25°C | | 0.1 | | pA/√Hz |
| $B_1$ | Unity-gain bandwidth | See Figure 3 | 25°C | | 2.8 | | MHz |
| $\phi_m$ | Phase margin at unity gain | See Figure 3 | 25°C | | 52° | | |

† Full range is –40°C to 125°C.

## PARAMETER MEASUREMENT INFORMATION

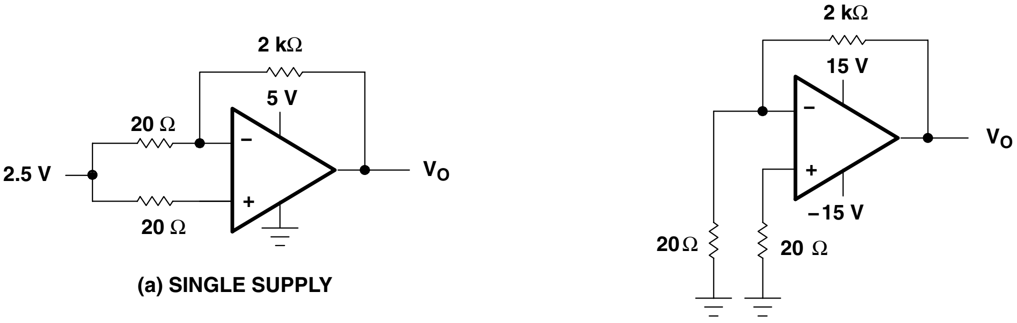


(a) SINGLE SUPPLY

(b) SPLIT SUPPLY

NOTE A: $C_L$ includes fixture capacitance.

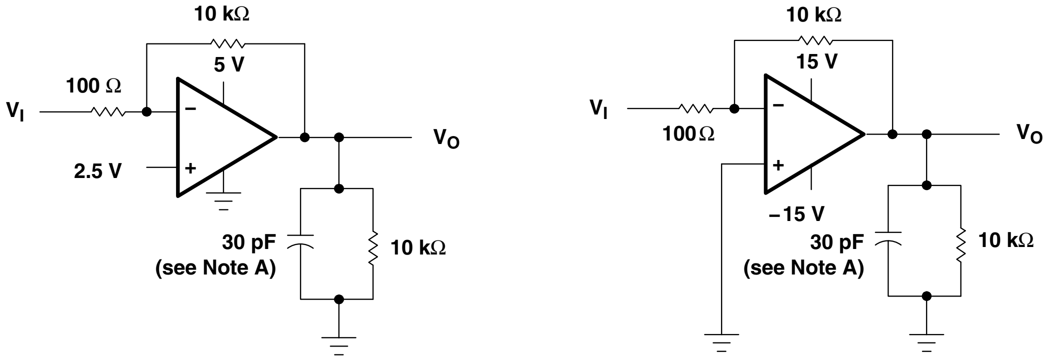
Figure 1. Slew-Rate Test Circuit



(a) SINGLE SUPPLY

(b) SPLIT SUPPLY

Figure 2. Noise-Voltage Test Circuit



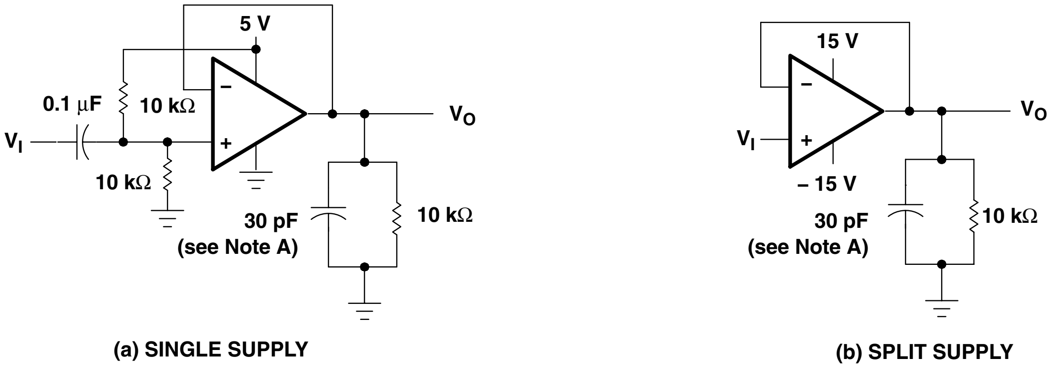
(a) SINGLE SUPPLY

(b) SPLIT SUPPLY

NOTE A: $C_L$ includes fixture capacitance.

Figure 3. Unity-Gain Bandwidth and Phase-Margin Test Circuit

## PARAMETER MEASUREMENT INFORMATION



NOTE A: $C_L$ includes fixture capacitance.

**Figure 4. Small-Signal Pulse-Response Test Circuit**

### typical values

Typical values presented in this data sheet represent the median (50% point) of device parametric performance.

## TYPICAL CHARACTERISTICS

### Table of Graphs

| | | | FIGURE |
|---|---|---|---|
| $V_{IO}$ | Input offset voltage | Distribution | 5, 6, 7 |
| $I_{IB}$ | Input bias current | vs Common-mode input voltage<br>vs Free-air temperature | 8, 9, 10<br>11, 12, 13 |
| $I_I$ | Input current | vs Differential input voltage | 14 |
| $V_{OM}$ | Maximum peak output voltage | vs Output current<br>vs Free-air temperature | 15, 16, 17<br>18 |
| $V_{OH}$ | High-level output voltage | vs High-level output current<br>vs Free-air temperature | 19, 20<br>21 |
| $V_{OL}$ | Low-level output voltage | vs Low-level output current<br>vs Free-air temperature | 22<br>23 |
| $V_{O(PP)}$ | Maximum peak-to-peak output voltage | vs Frequency | 24, 25 |
| $A_{VD}$ | Large-signal differential voltage amplification | vs Frequency<br>vs Free-air temperature | 26<br>27, 28, 29 |
| $I_{OS}$ | Short-circuit output current | vs Supply voltage<br>vs Free-air temperature | 30 – 33<br>34 – 37 |
| $I_{CC}$ | Supply current | vs Supply voltage<br>vs Free-air temperature | 38, 39, 40<br>41, 42, 43 |
| CMRR | Common-mode rejection ratio | vs Frequency | 44, 45, 46 |
| SR | Slew rate | vs Free-air temperature | 47, 48, 49 |
| | Voltage-follower small-signal pulse response | | 50, 51 |
| | Voltage-follower large-signal pulse response | | 52 – 57 |
| $V_{N(PP)}$ | Peak-to-peak equivalent input noise voltage | 0.1 to 1 Hz<br>0.1 to 10 Hz | 58<br>59 |
| $V_n$ | Equivalent input noise voltage | vs Frequency | 60 |
| $B_1$ | Unity-gain bandwidth | vs Supply voltage<br>vs Free-air temperature | 61, 62<br>63, 64 |
| $\phi_m$ | Phase margin | vs Supply voltage<br>vs Load capacitance<br>vs Free-air temperature | 65, 66<br>67, 68<br>69, 70 |
| | Phase shift | vs Frequency | 26 |

## TYPICAL CHARACTERISTICS

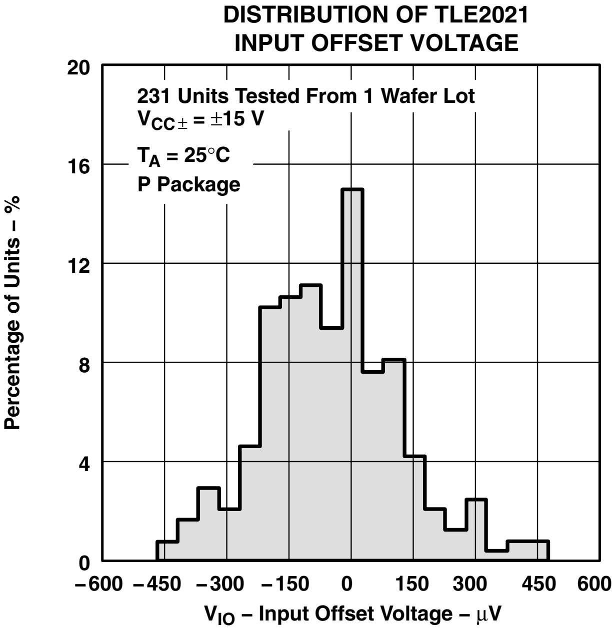


Figure 5

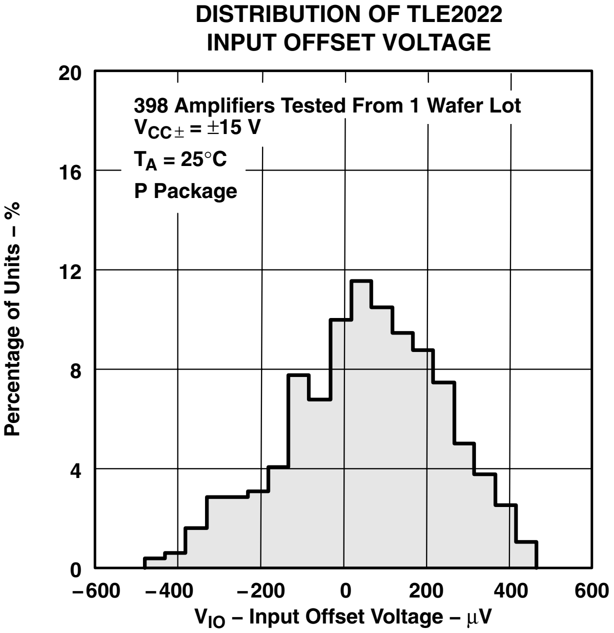


Figure 6

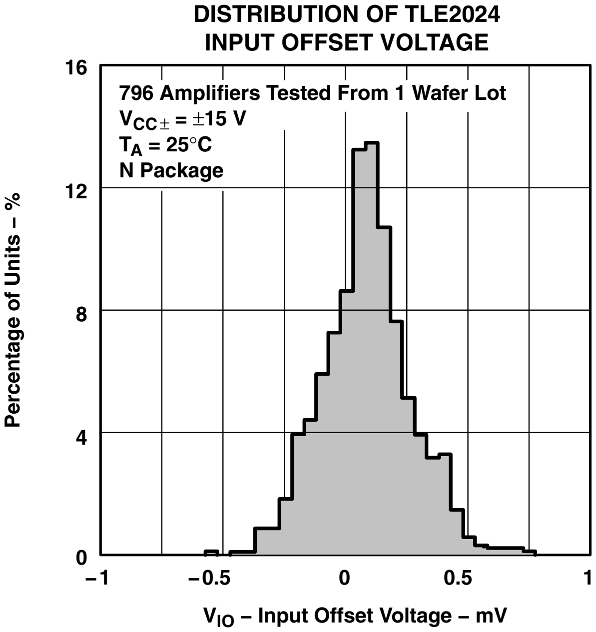


Figure 7

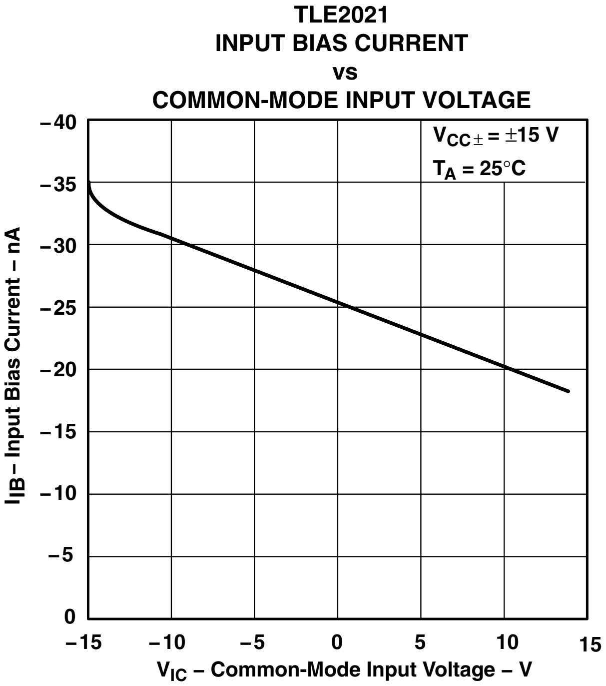


Figure 8

## TYPICAL CHARACTERISTICS

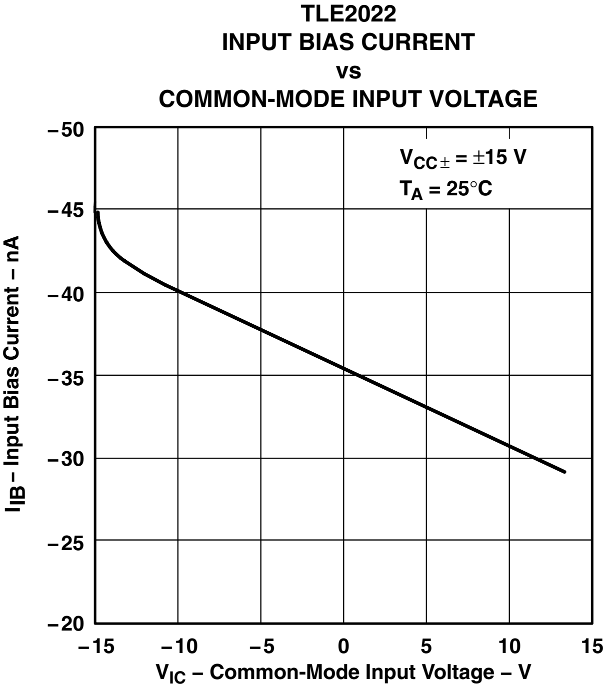


Figure 9

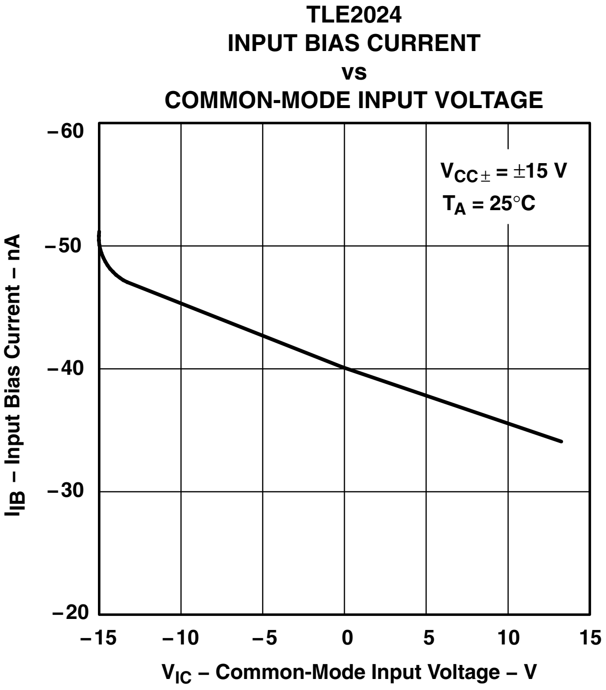


Figure 10

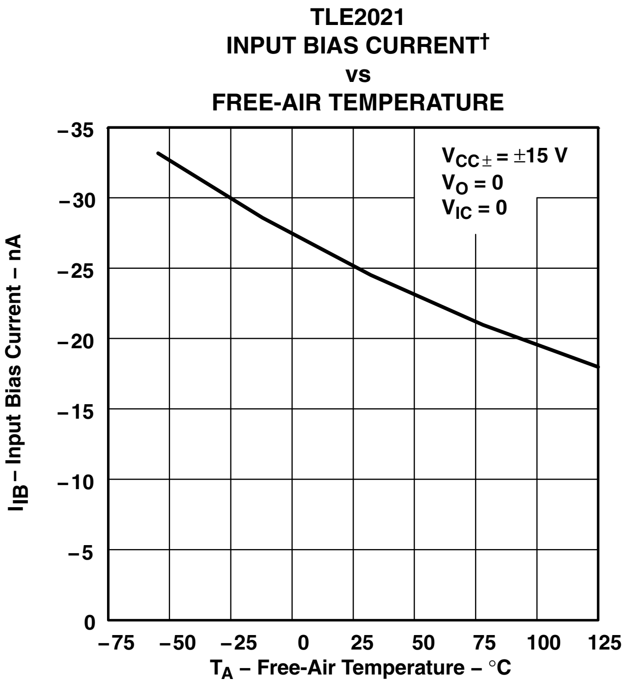


Figure 11

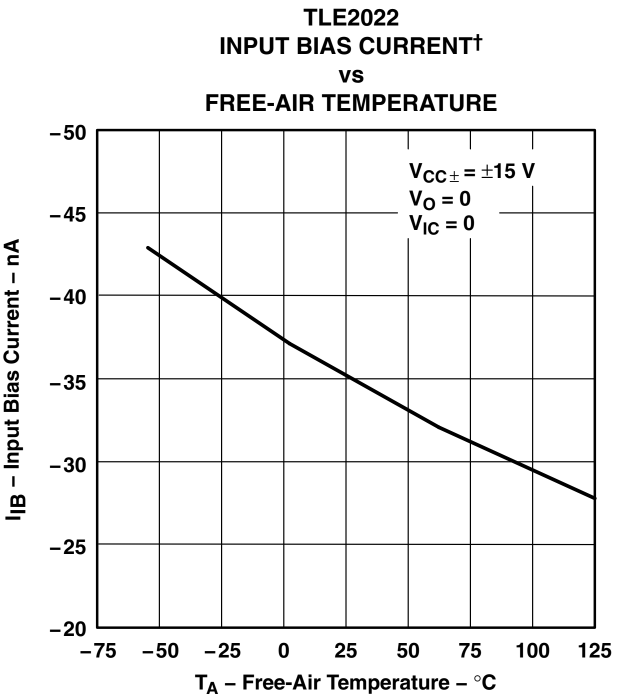


Figure 12

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

## TYPICAL CHARACTERISTICS

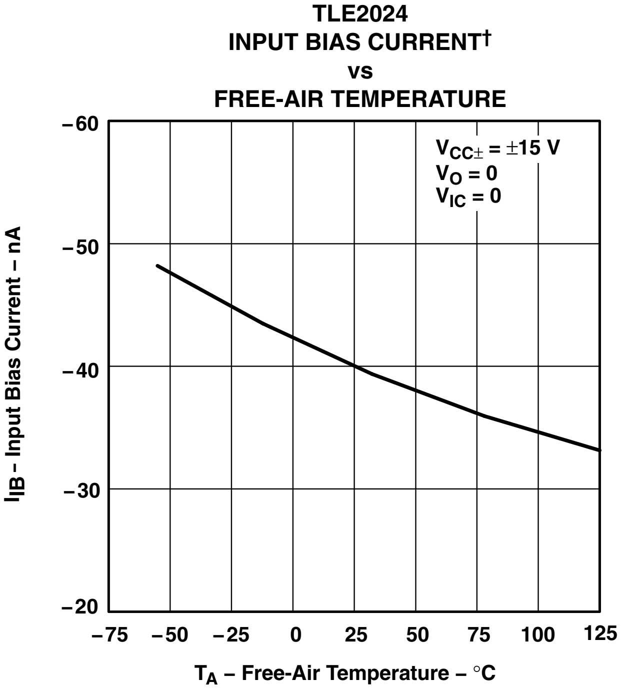


Figure 13

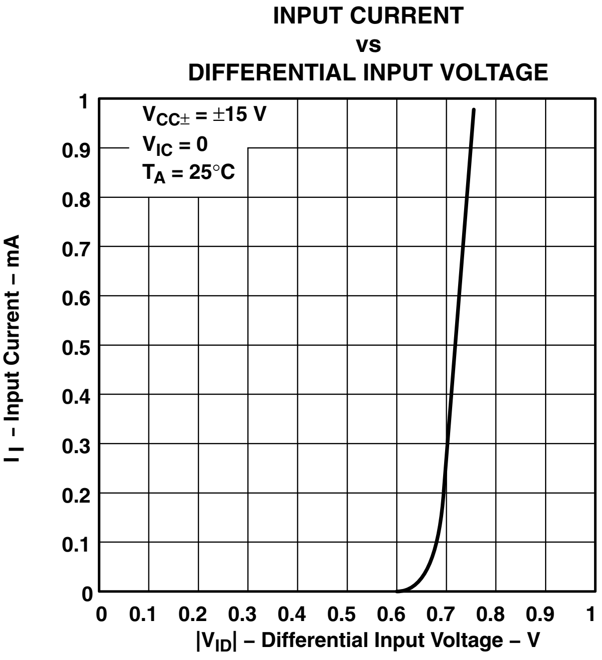


Figure 14

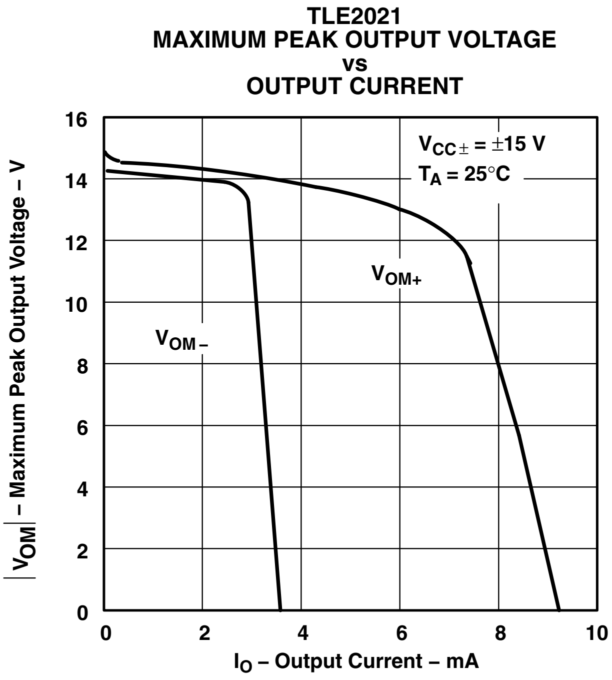


Figure 15

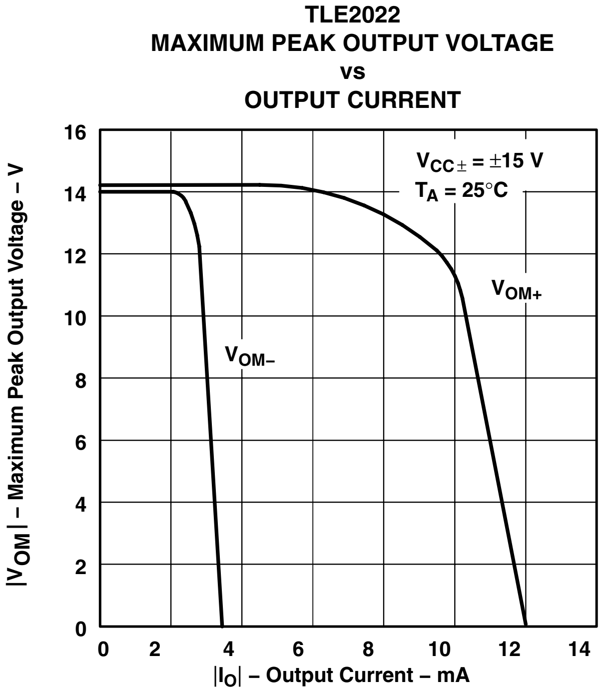


Figure 16

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

## TYPICAL CHARACTERISTICS

TLE2024
MAXIMUM PEAK OUTPUT VOLTAGE
vs
OUTPUT CURRENT

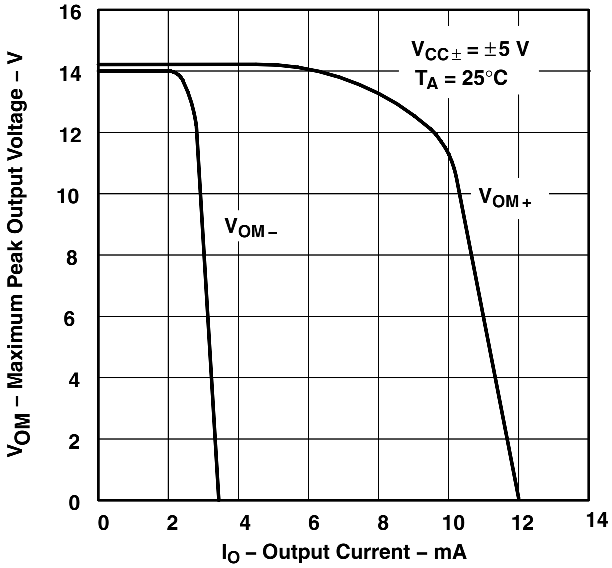

Figure 17

MAXIMUM PEAK OUTPUT VOLTAGE†
vs
FREE-AIR TEMPERATURE

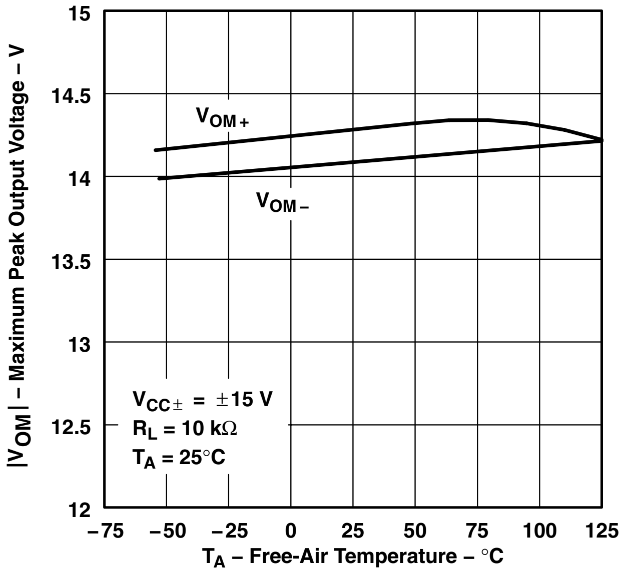

Figure 18

TLE2021
HIGH-LEVEL OUTPUT VOLTAGE
vs
HIGH-LEVEL OUTPUT CURRENT

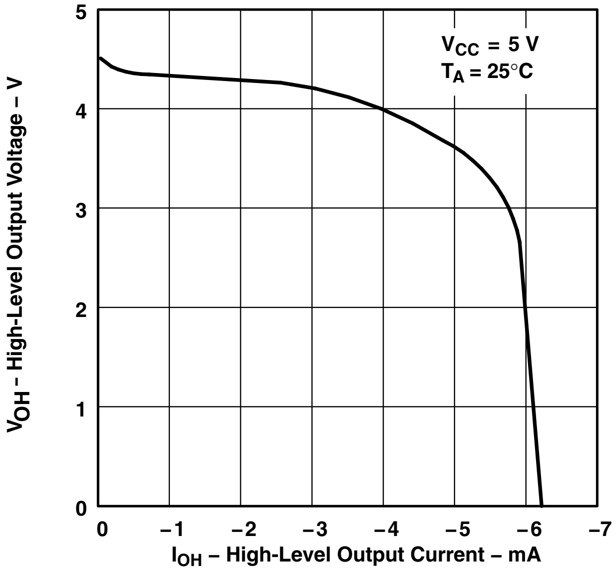

Figure 19

TLE2022 AND TLE2024
HIGH-LEVEL OUTPUT VOLTAGE
vs
HIGH-LEVEL OUTPUT CURRENT

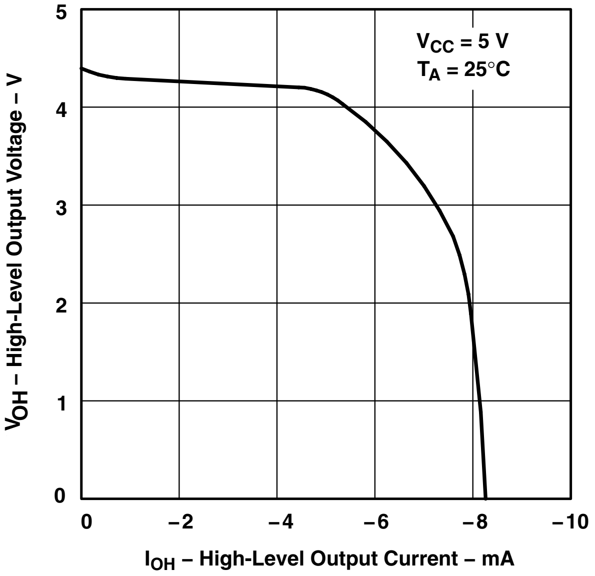

Figure 20

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

## TYPICAL CHARACTERISTICS

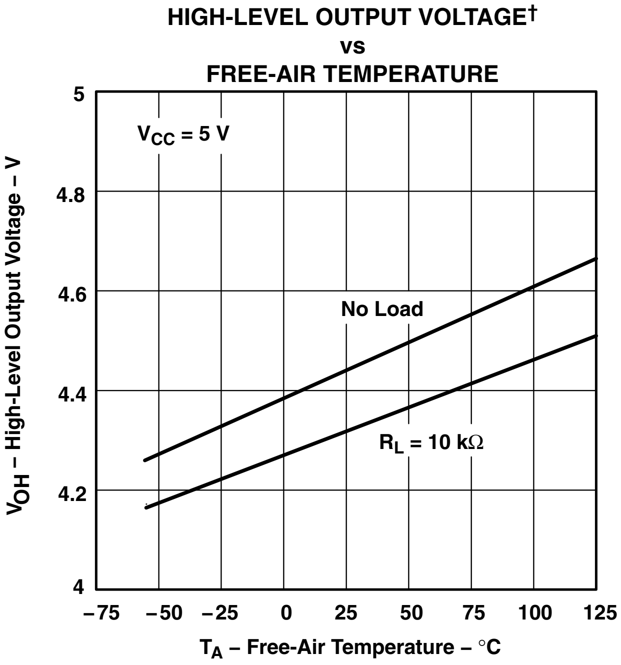

Figure 21

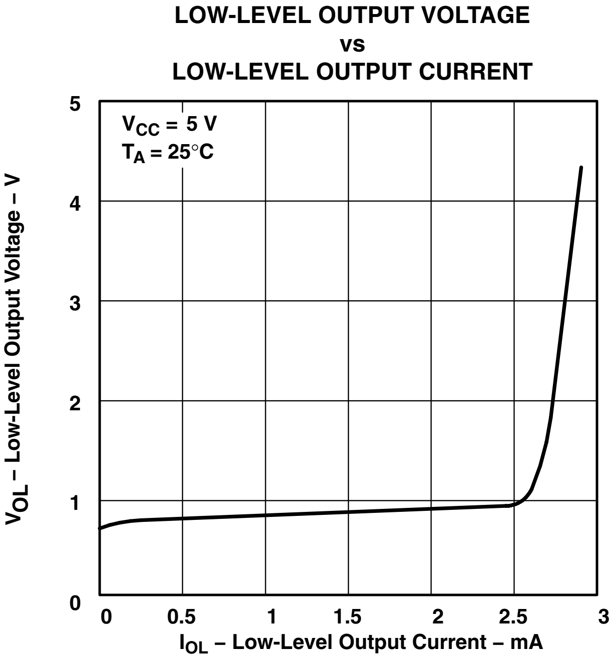

Figure 22

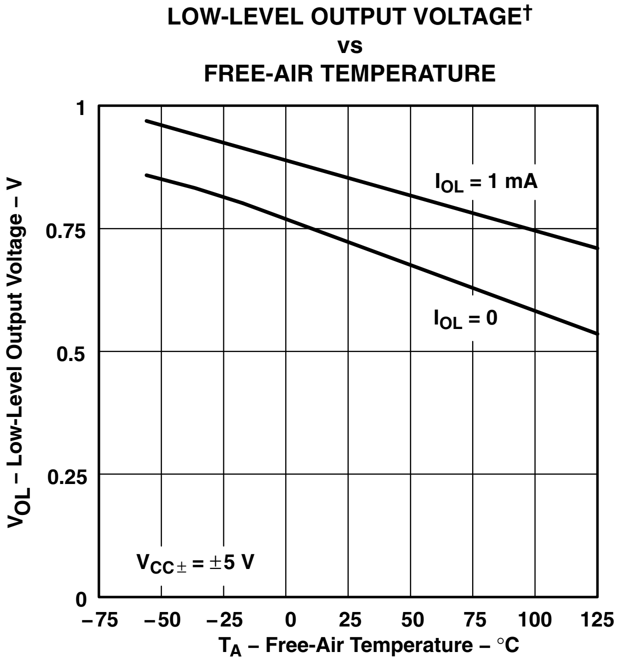

Figure 23

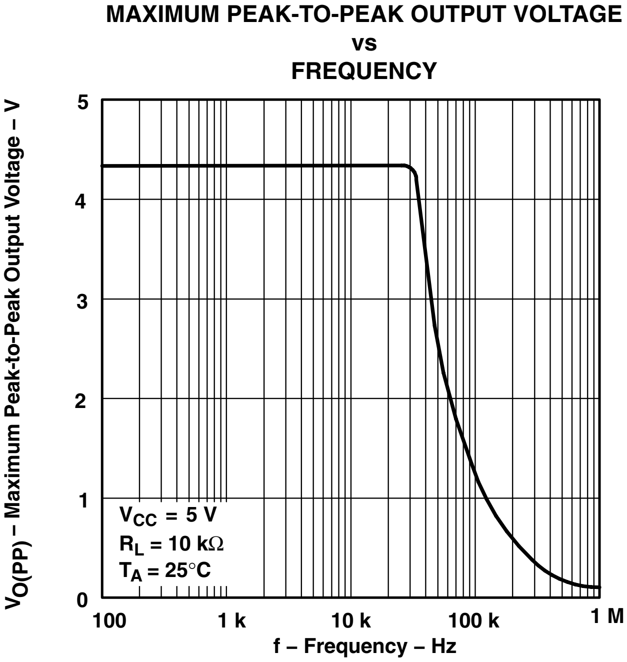

Figure 24

---

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

## TYPICAL CHARACTERISTICS

### MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE vs FREQUENCY

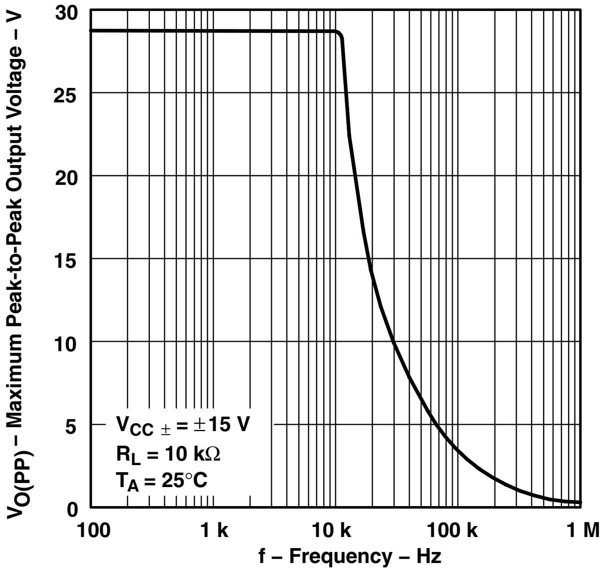

Figure 25

### LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION AND PHASE SHIFT vs FREQUENCY

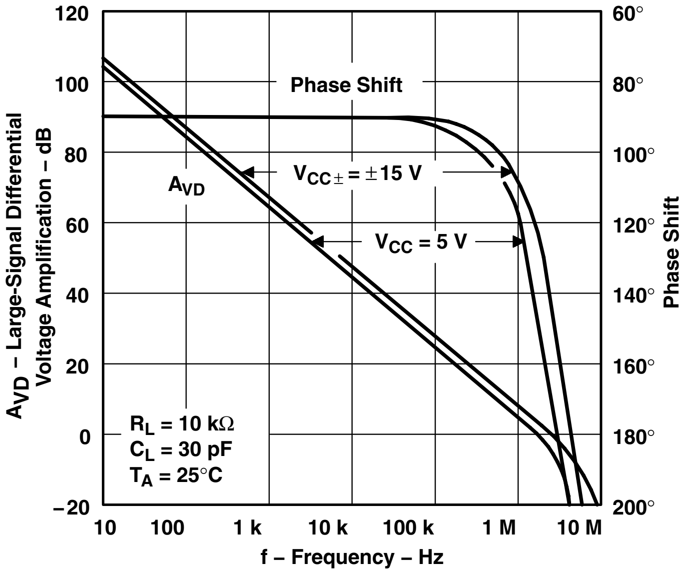

Figure 26

## TYPICAL CHARACTERISTICS

**TLE2021
LARGE-SCALE DIFFERENTIAL VOLTAGE AMPLIFICATION†
vs
FREE-AIR TEMPERATURE**

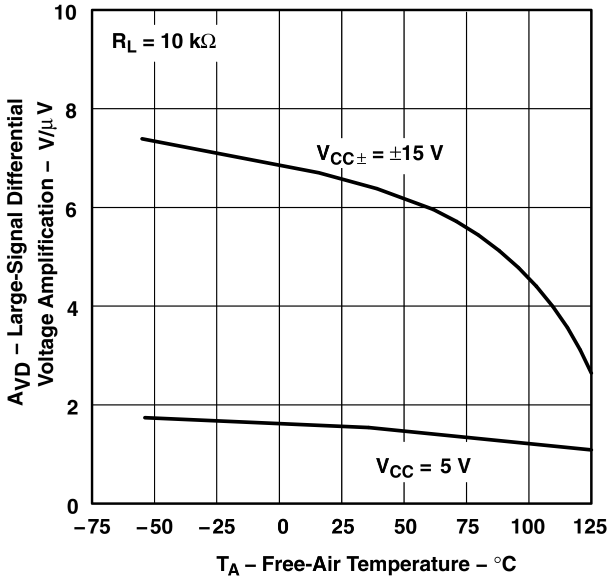

Figure 27

**TLE2022
LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION†
vs
FREE-AIR TEMPERATURE**

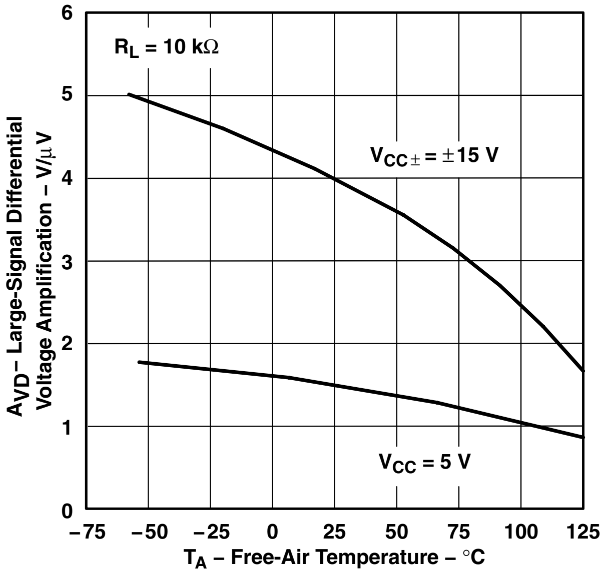

Figure 28

**TLE2024
LARGE-SCALE DIFFERENTIAL VOLTAGE AMPLIFICATION†
vs
FREE-AIR TEMPERATURE**

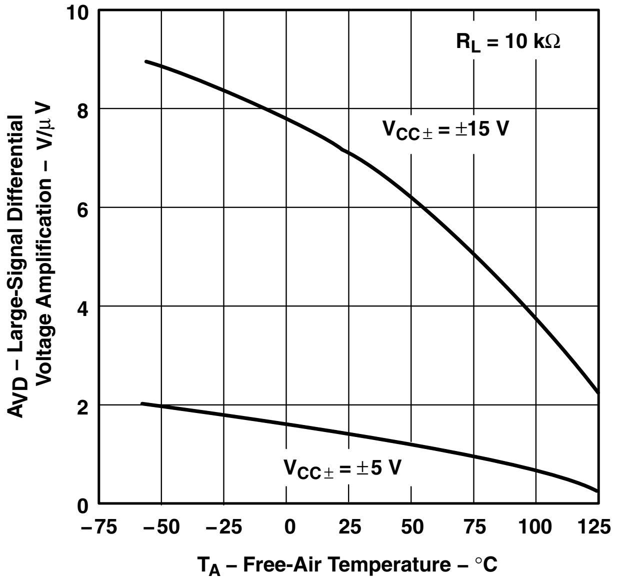

Figure 29

**TLE2021
SHORT-CIRCUIT OUTPUT CURRENT
vs
SUPPLY VOLTAGE**

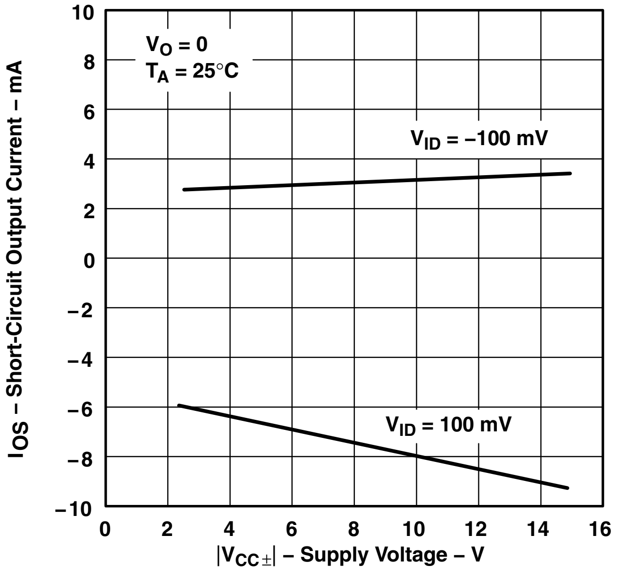

Figure 30

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

## TYPICAL CHARACTERISTICS

### TLE2022 AND TLE2024 SHORT-CIRCUIT OUTPUT CURRENT vs SUPPLY VOLTAGE

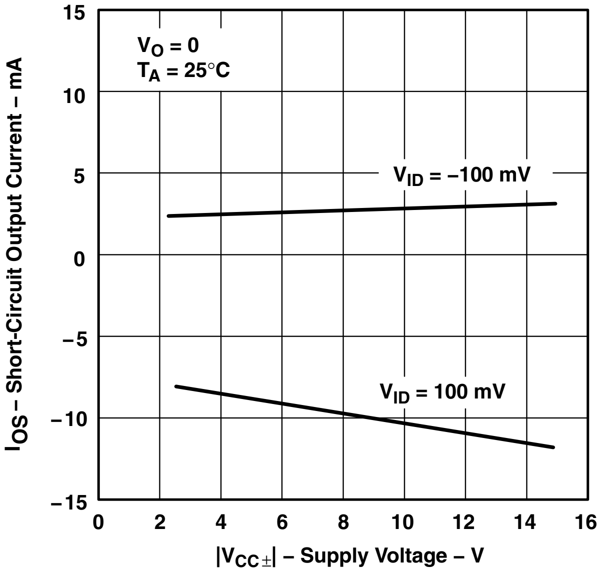

Figure 31

### TLE2021 SHORT-CIRCUIT OUTPUT CURRENT vs SUPPLY VOLTAGE

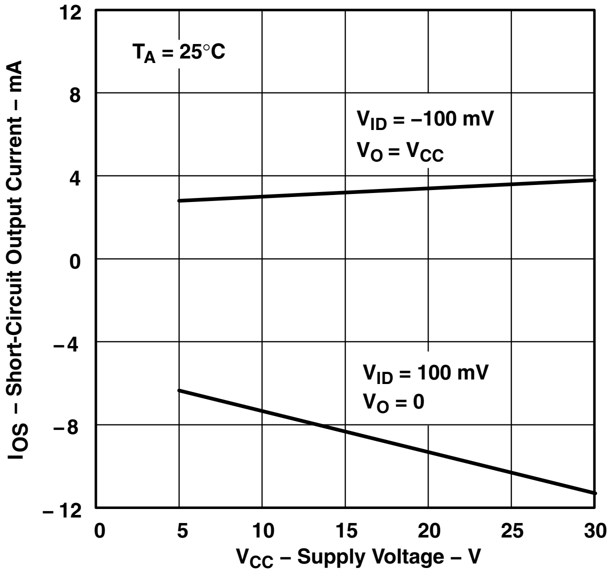

Figure 32

### TLE2022 AND TLE2024 SHORT-CIRCUIT OUTPUT CURRENT vs SUPPLY VOLTAGE

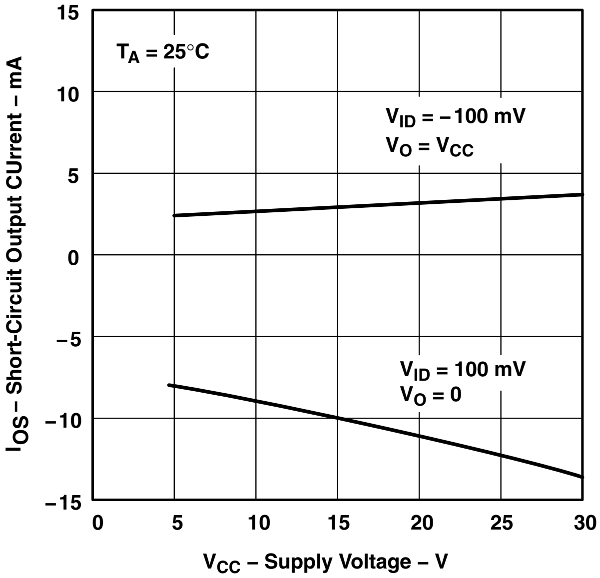

Figure 33

### TLE2021 SHORT-CIRCUIT OUTPUT CURRENT† vs FREE-AIR TEMPERATURE

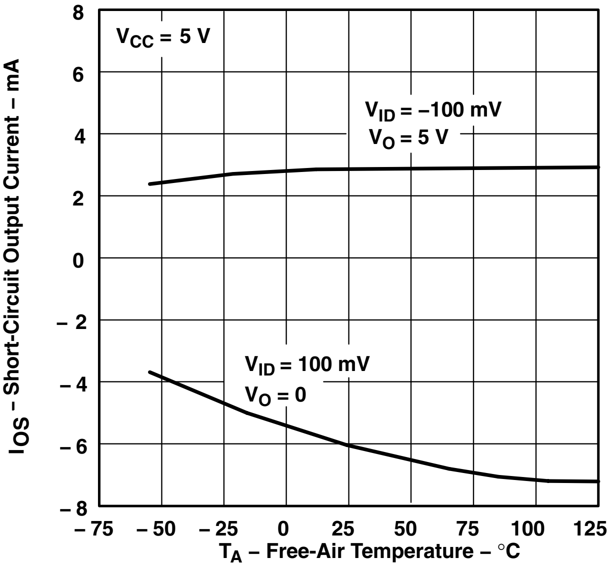

Figure 34

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

## TYPICAL CHARACTERISTICS

### TLE2022 AND TLE2024 SHORT-CIRCUIT OUTPUT CURRENT† vs FREE-AIR TEMPERATURE

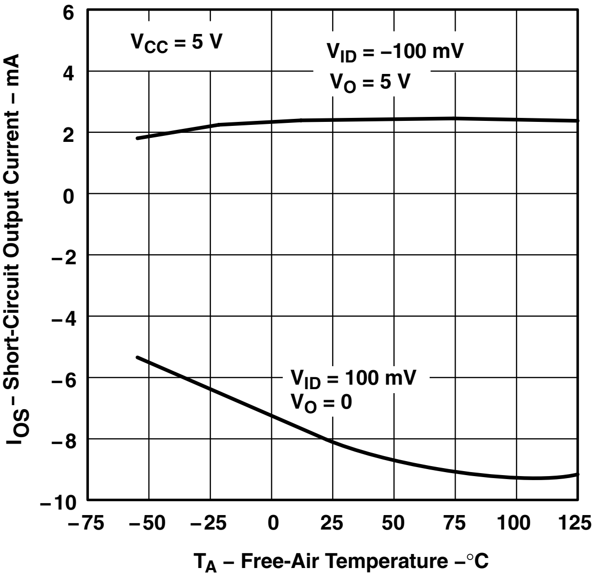

Figure 35

### TLE2021 SHORT-CIRCUIT OUTPUT CURRENT† vs FREE-AIR TEMPERATURE

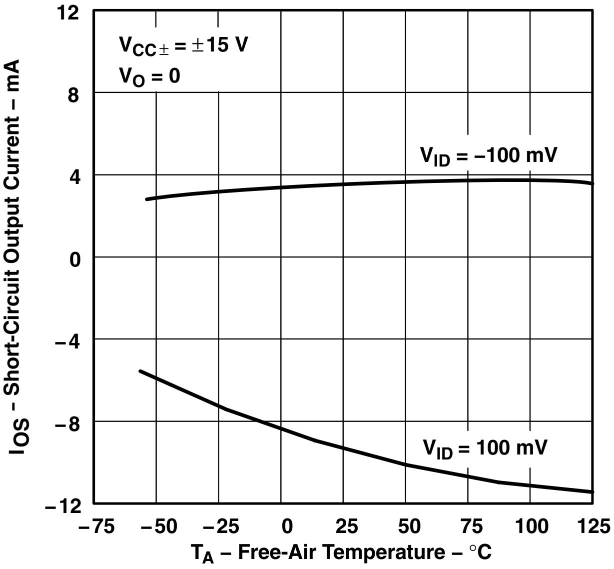

Figure 36

### TLE2022 AND TLE2024 SHORT-CIRCUIT OUTPUT CURRENT† vs FREE-AIR TEMPERATURE

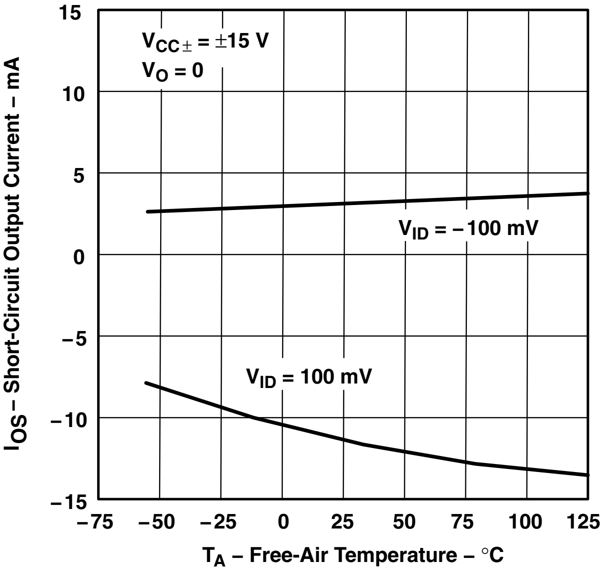

Figure 37

### TLE2021 SUPPLY CURRENT vs SUPPLY VOLTAGE

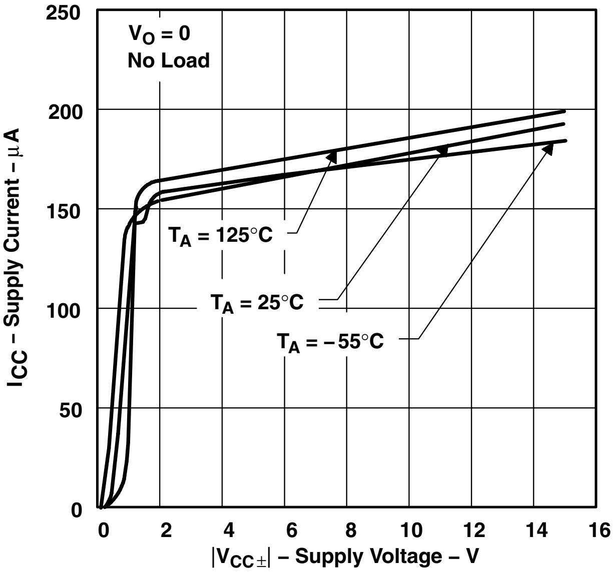

Figure 38

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

## TYPICAL CHARACTERISTICS

### TLE2022 SUPPLY CURRENT vs SUPPLY VOLTAGE

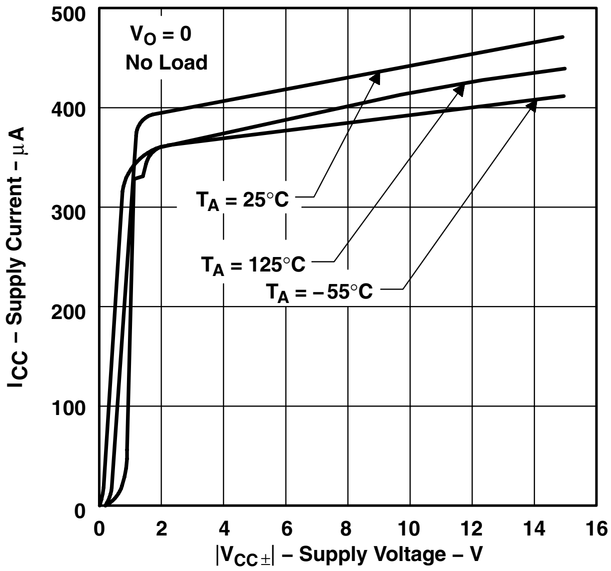

Figure 39

### TLE2024 SUPPLY CURRENT vs SUPPLY VOLTAGE

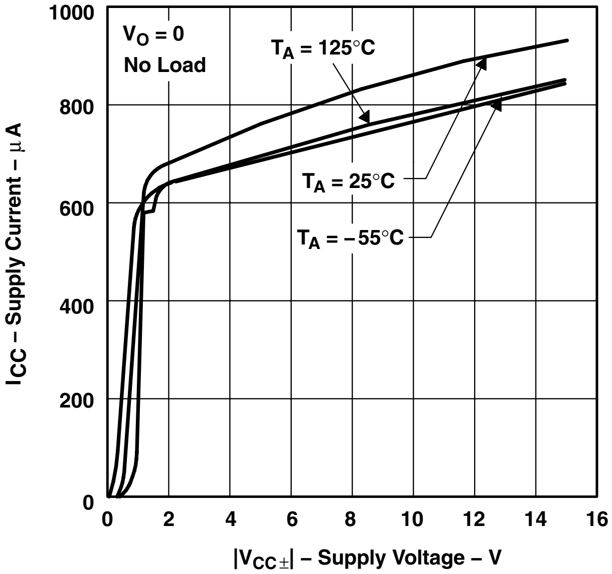

Figure 40

### TLE2021 SUPPLY CURRENT† vs FREE-AIR TEMPERATURE

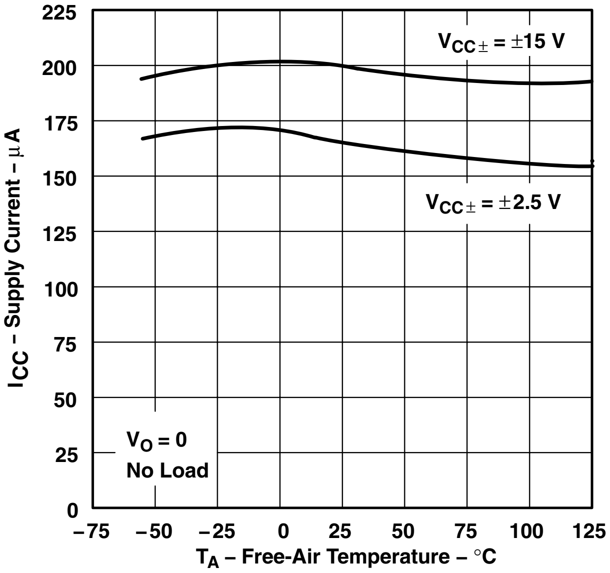

Figure 41

### TLE2022 SUPPLY CURRENT† vs FREE-AIR TEMPERATURE

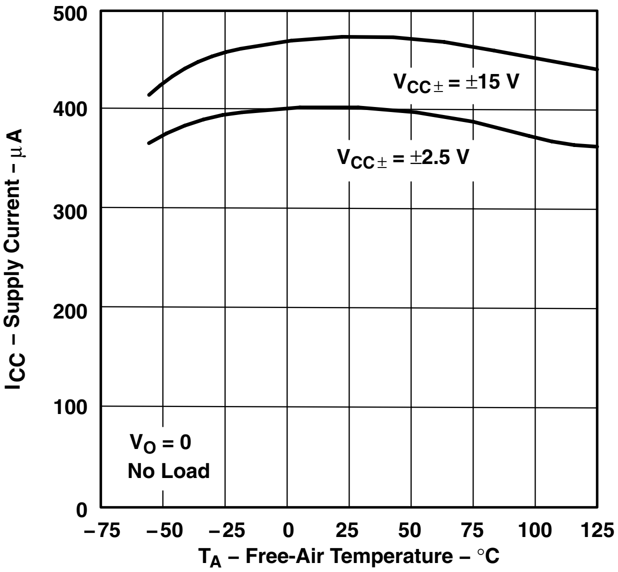

Figure 42

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

## TYPICAL CHARACTERISTICS

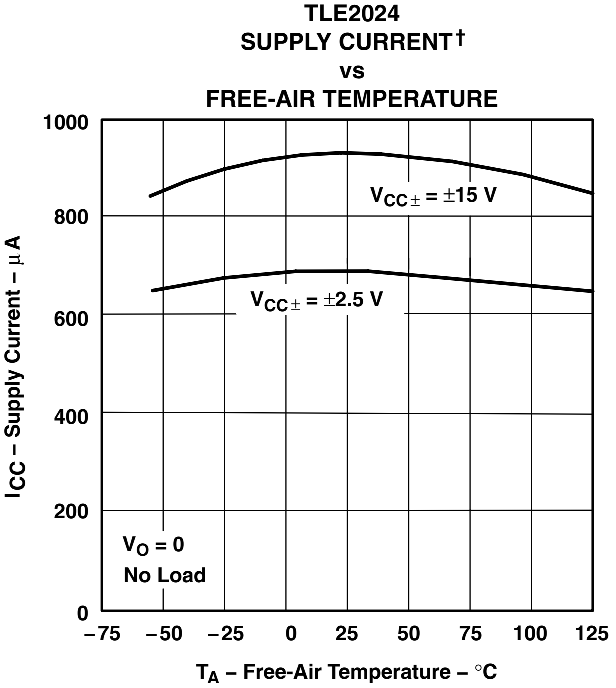
TLE2024
SUPPLY CURRENT†
vs
FREE-AIR TEMPERATURE

Figure 43

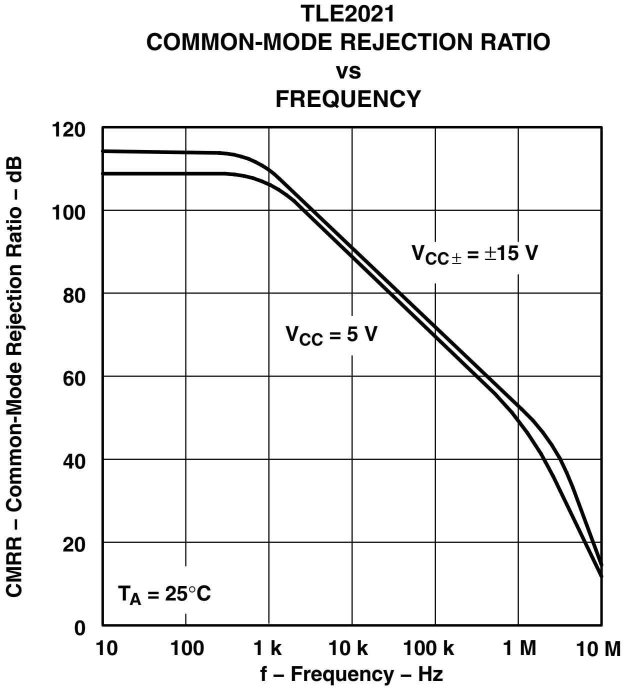
TLE2021
COMMON-MODE REJECTION RATIO
vs
FREQUENCY

Figure 44

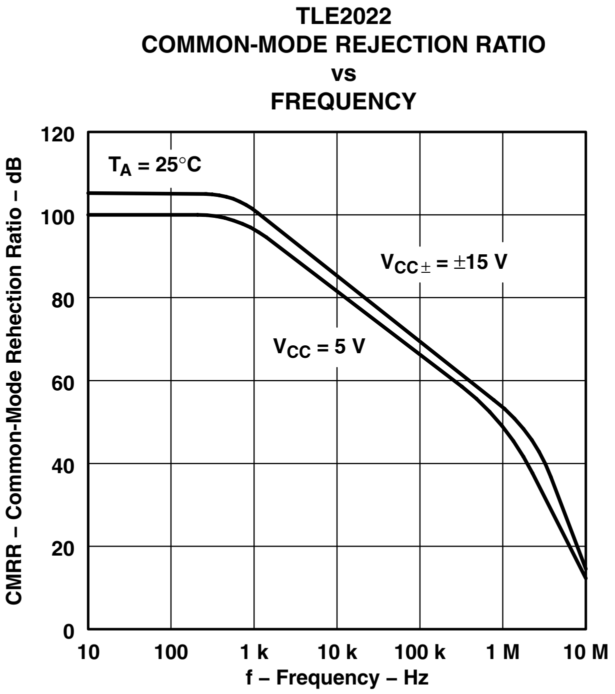
TLE2022
COMMON-MODE REJECTION RATIO
vs
FREQUENCY

Figure 45

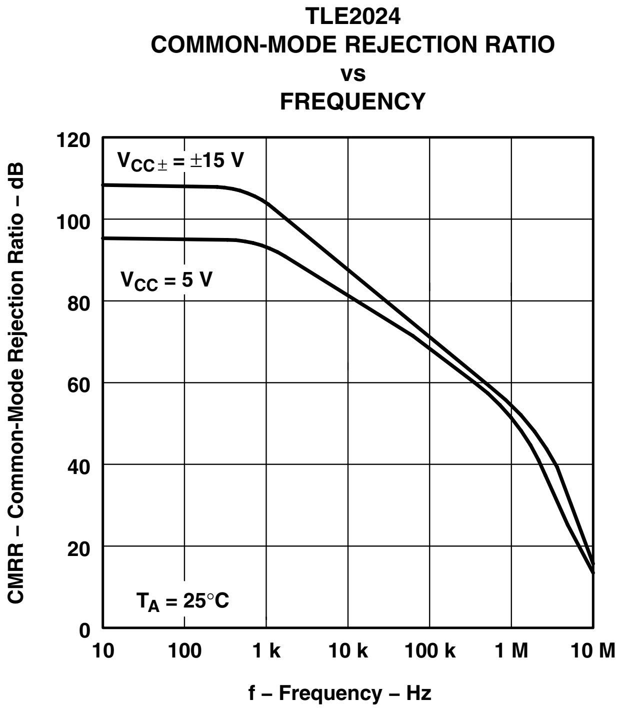
TLE2024
COMMON-MODE REJECTION RATIO
vs
FREQUENCY

Figure 46

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

## TYPICAL CHARACTERISTICS

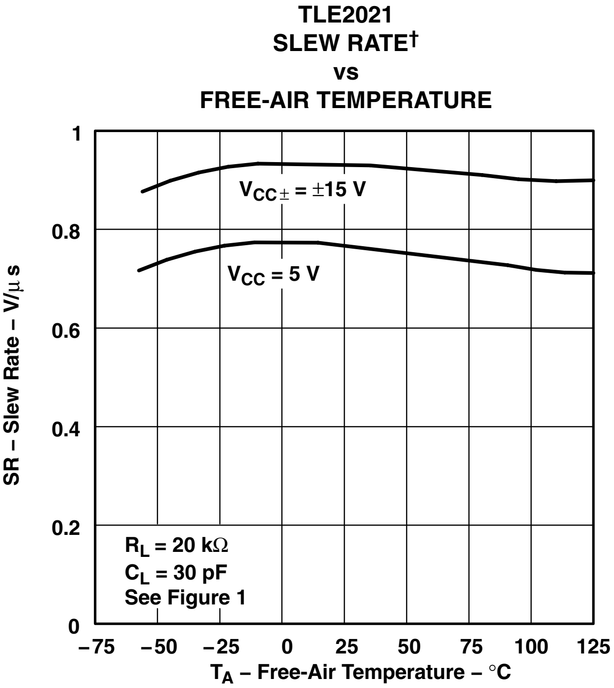

Figure 47

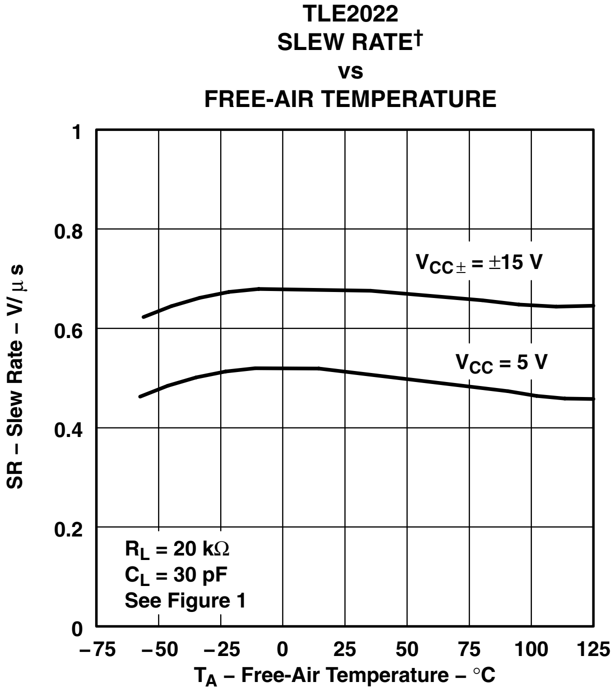

Figure 48

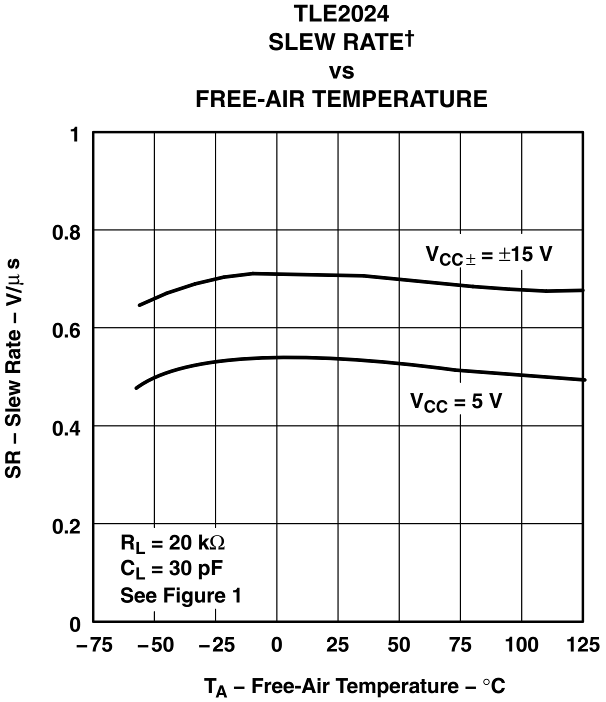

Figure 49

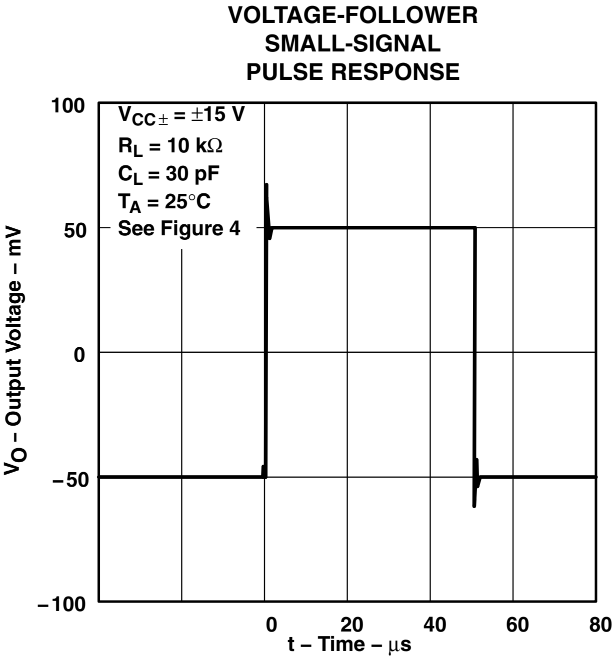

Figure 50

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

## TYPICAL CHARACTERISTICS

VOLTAGE-FOLLOWER
SMALL-SIGNAL
PULSE RESPONSE

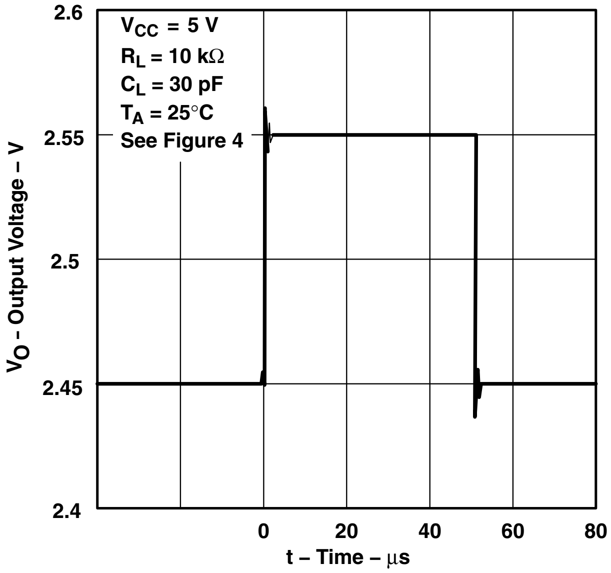

Figure 51

TLE2021
VOLTAGE-FOLLOWER LARGE-SIGNAL
PULSE RESPONSE

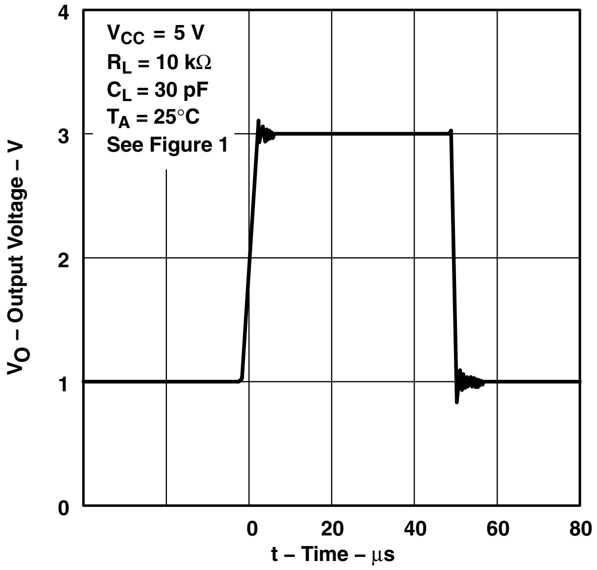

Figure 52

TLE2022
VOLTAGE-FOLLOWER LARGE-SIGNAL
PULSE RESPONSE

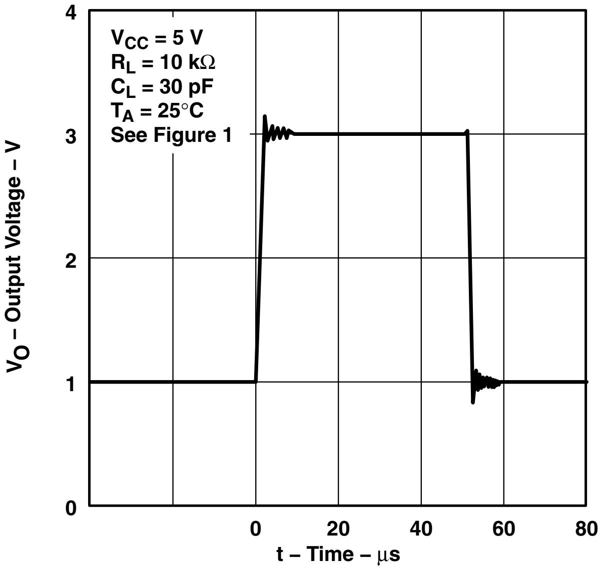

Figure 53

TLE2024
VOLTAGE-FOLLOWER LARGE-SCALE
PULSE RESPONSE

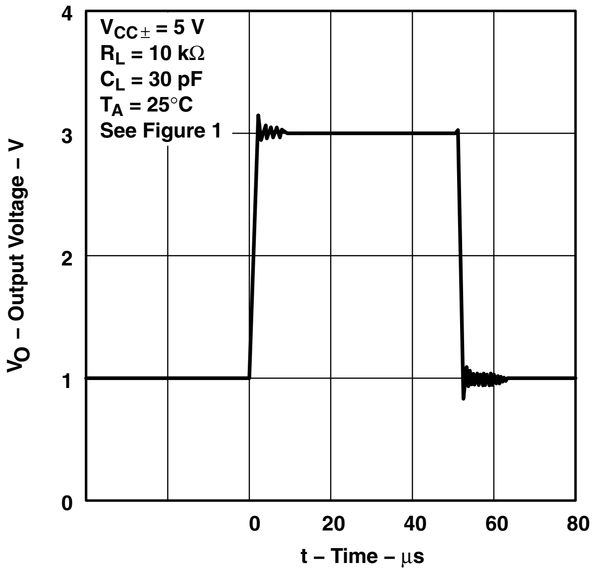

Figure 54

## TYPICAL CHARACTERISTICS

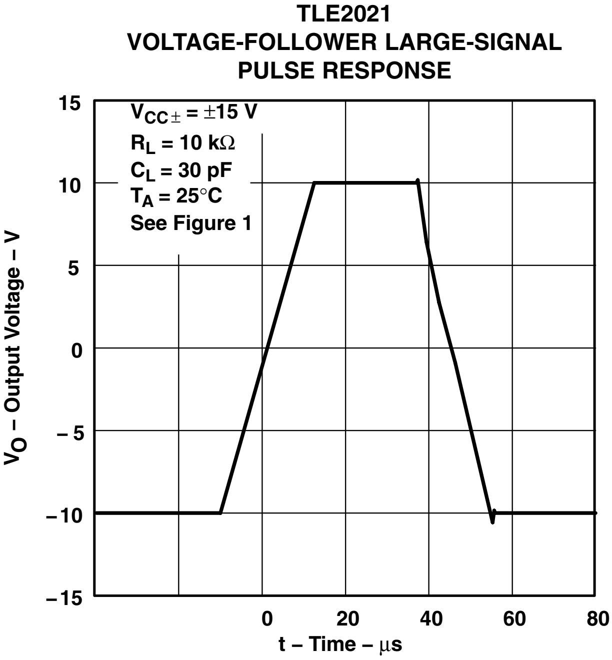

Figure 55

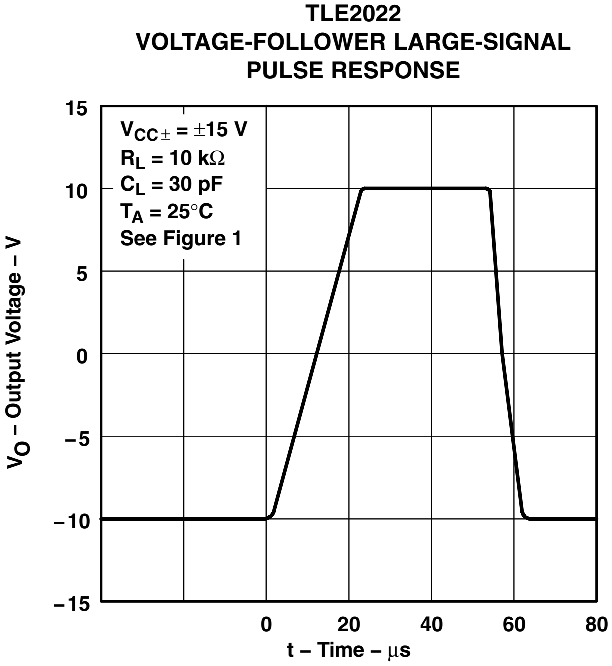

Figure 56

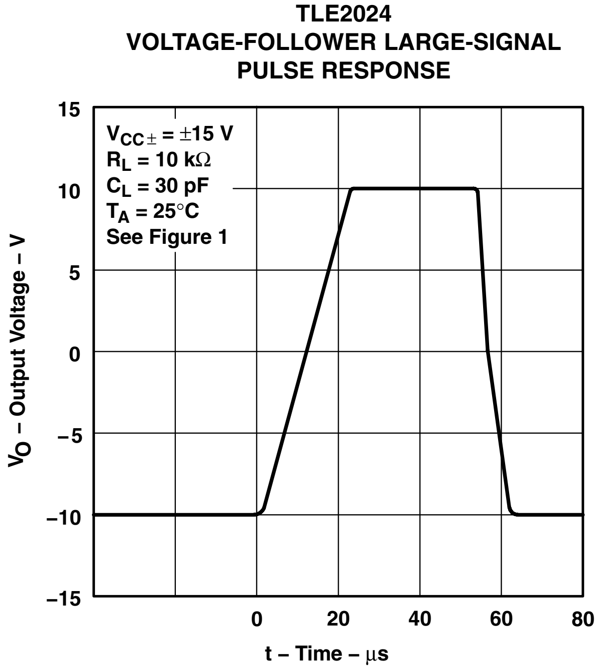

Figure 57

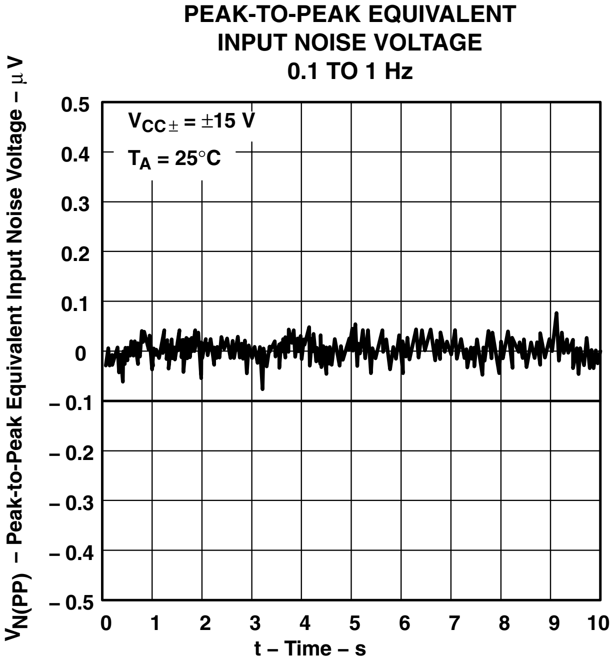

Figure 58

## TYPICAL CHARACTERISTICS

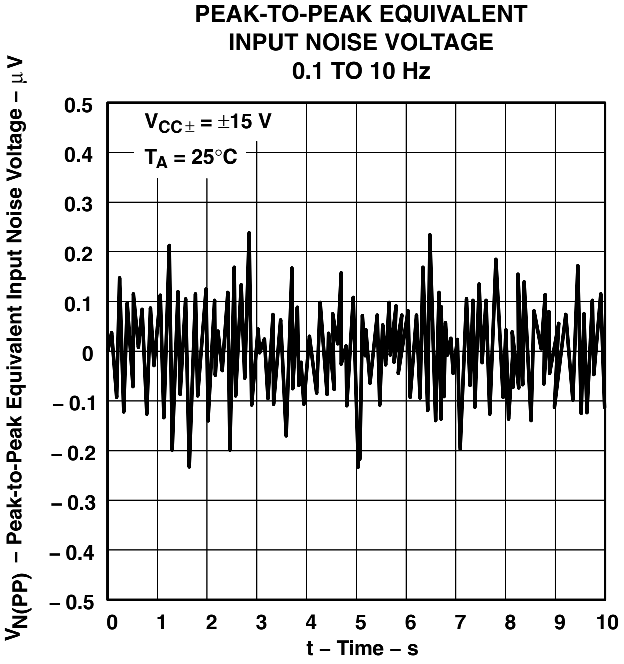

Figure 59

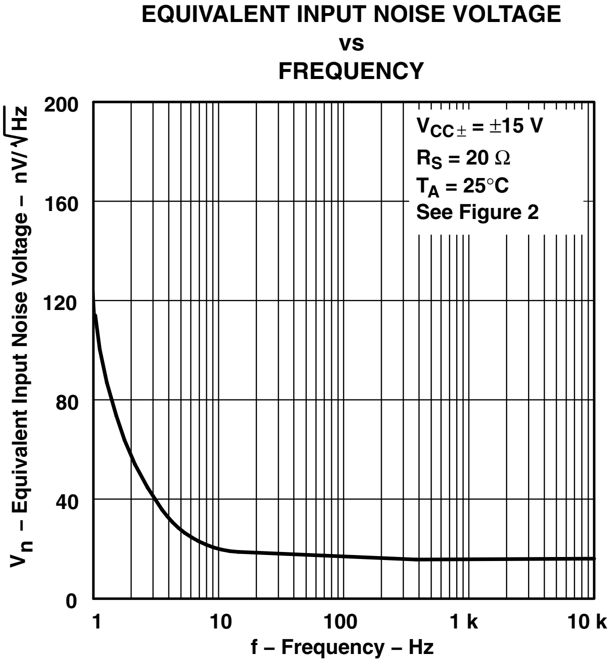

Figure 60

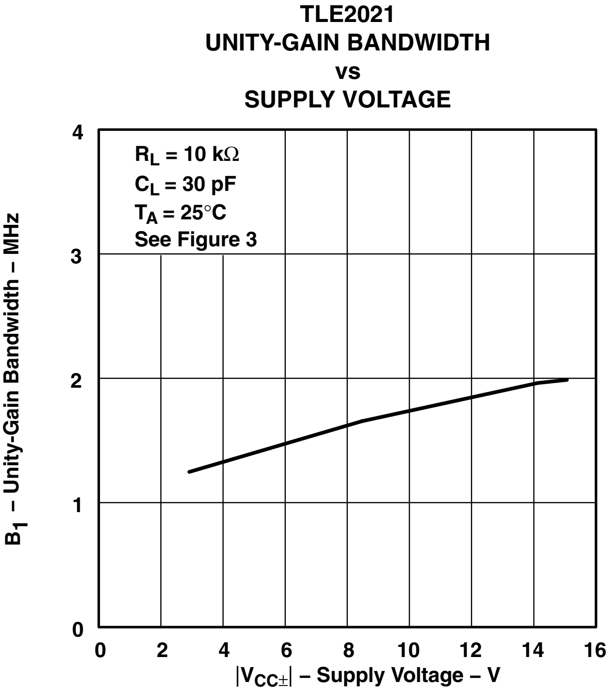

Figure 61

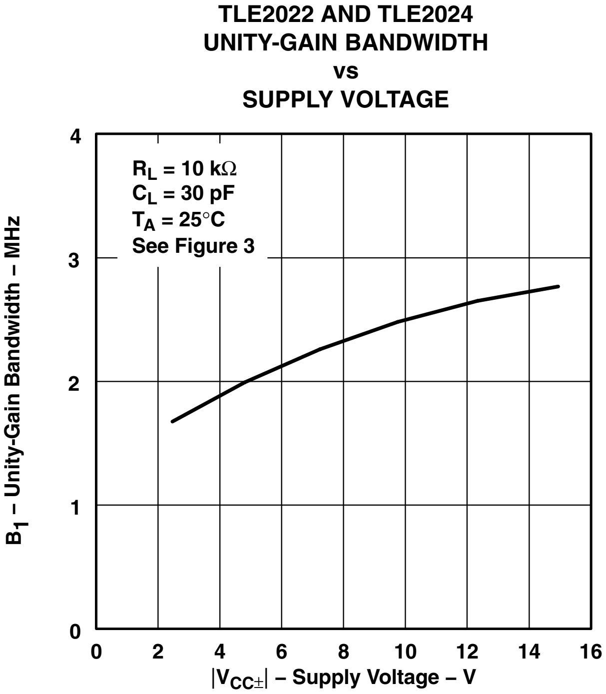

Figure 62

## TYPICAL CHARACTERISTICS

### TLE2021
### UNITY-GAIN BANDWIDTH†
### vs
### FREE-AIR TEMPERATURE

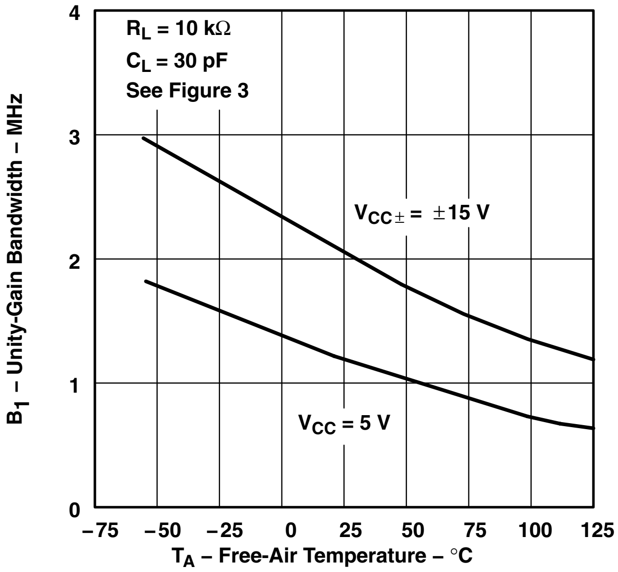

Figure 63

### TLE2022 AND TLE2024
### UNITY-GAIN BANDWIDTH†
### vs
### FREE-AIR TEMPERATURE

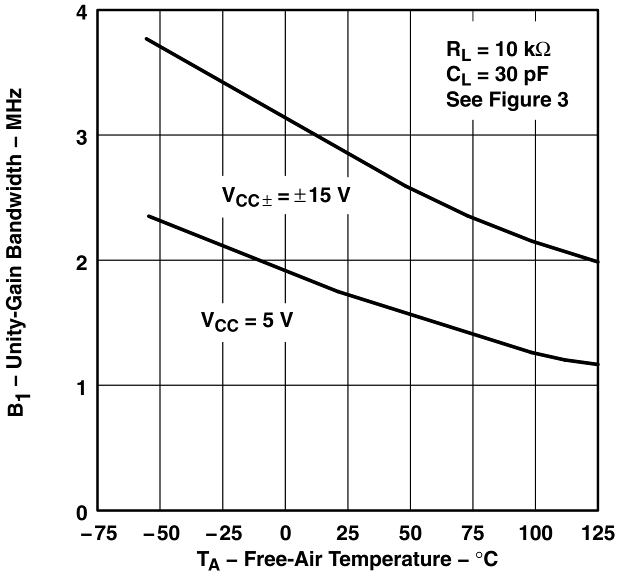

Figure 64

### TLE2021
### PHASE MARGIN
### vs
### SUPPLY VOLTAGE

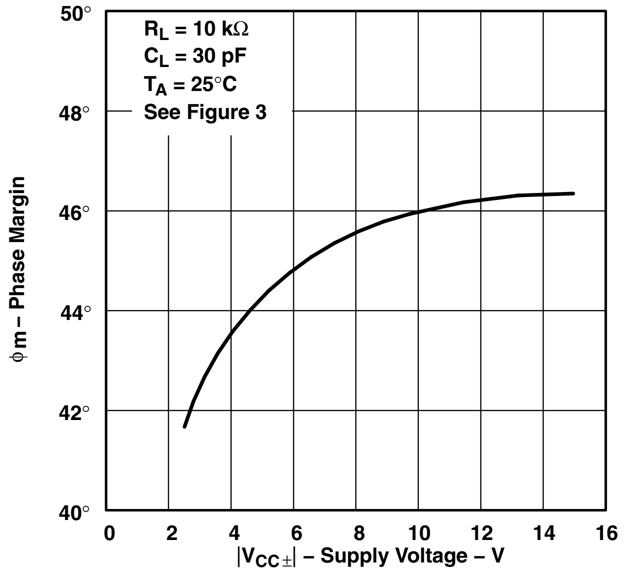

Figure 65

### TLE2022 AND TLE2024
### PHASE MARGIN
### vs
### SUPPLY VOLTAGE

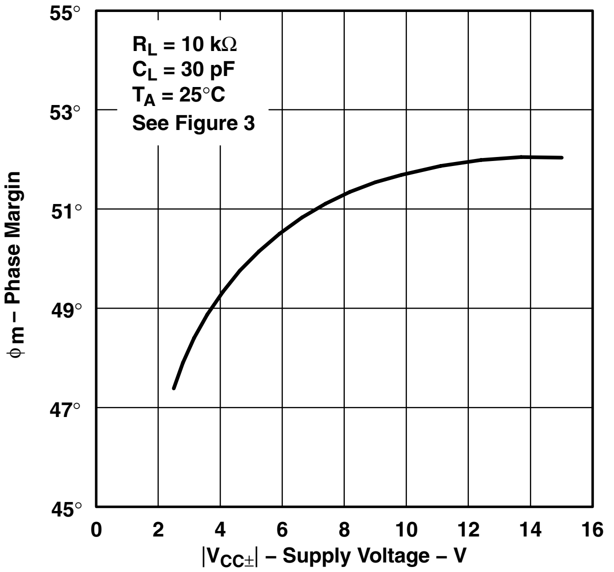

Figure 66

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

## TYPICAL CHARACTERISTICS

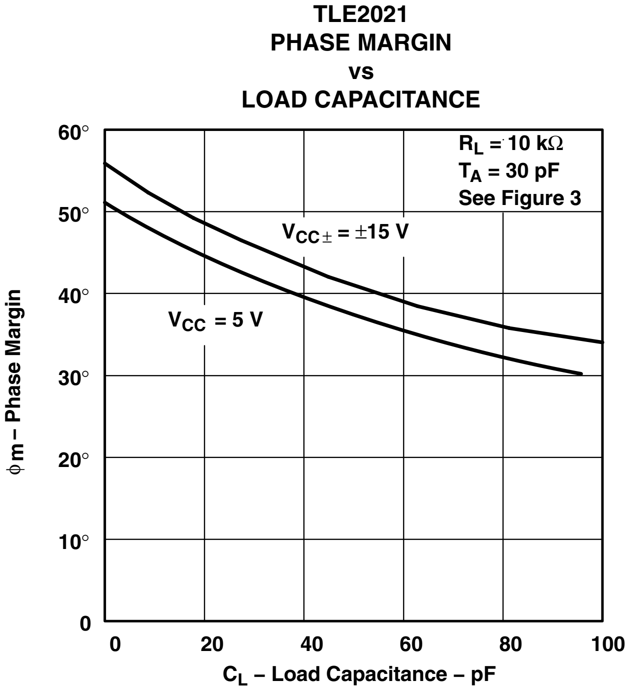

Figure 67

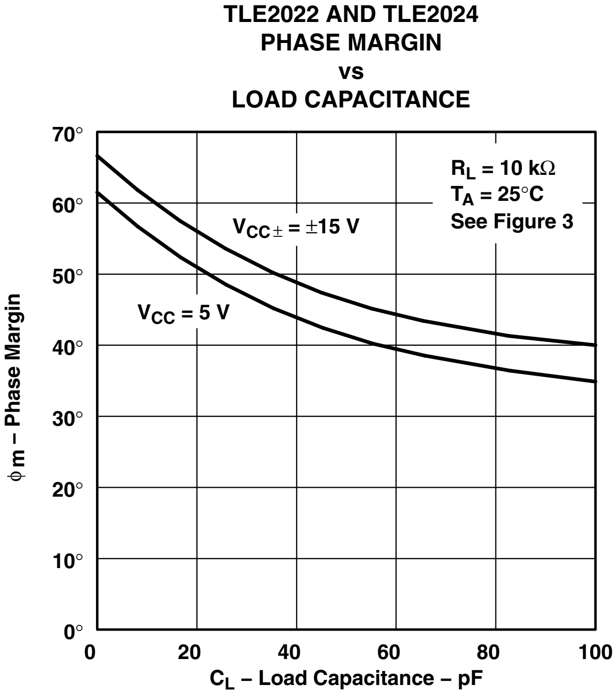

Figure 68

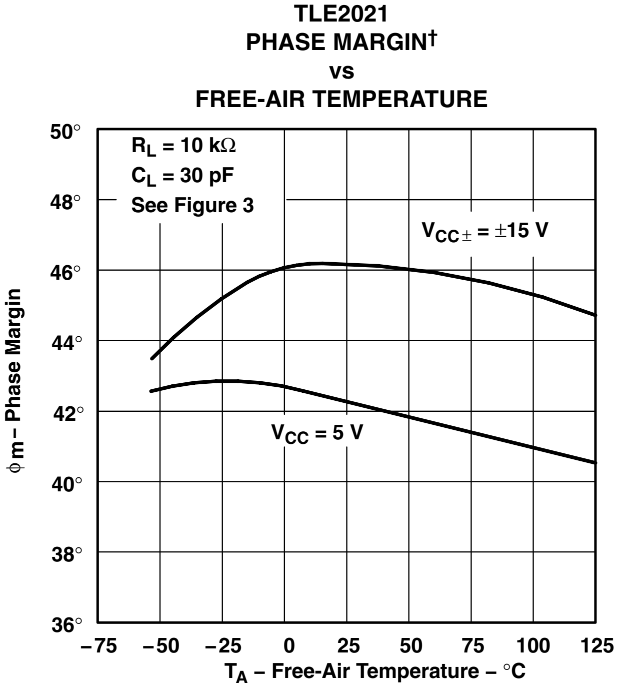

Figure 69

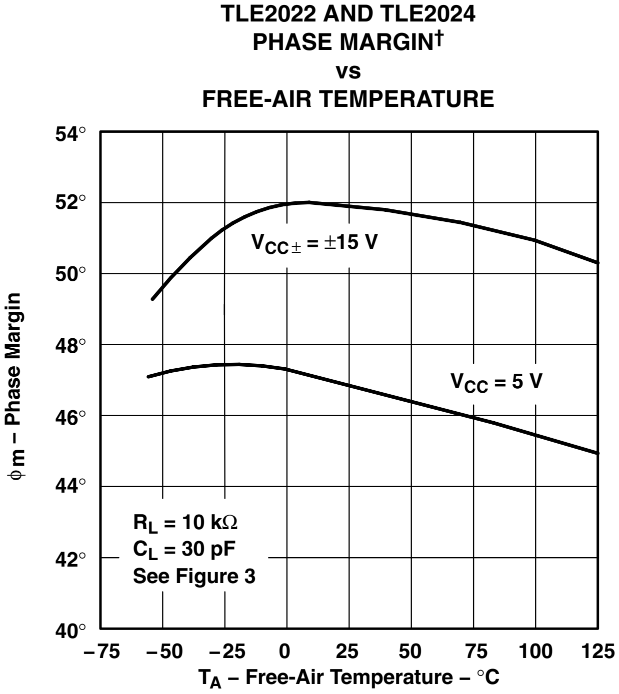

Figure 70

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

## APPLICATION INFORMATION

### voltage-follower applications

The TLE202x circuitry includes input-protection diodes to limit the voltage across the input transistors; however, no provision is made in the circuit to limit the current if these diodes are forward biased. This condition can occur when the device is operated in the voltage-follower configuration and driven with a fast, large-signal pulse. It is recommended that a feedback resistor be used to limit the current to a maximum of 1 mA to prevent degradation of the device. This feedback resistor forms a pole with the input capacitance of the device. For feedback resistor values greater than 10 kΩ, this pole degrades the amplifier phase margin. This problem can be alleviated by adding a capacitor (20 pF to 50 pF) in parallel with the feedback resistor (see Figure 71).

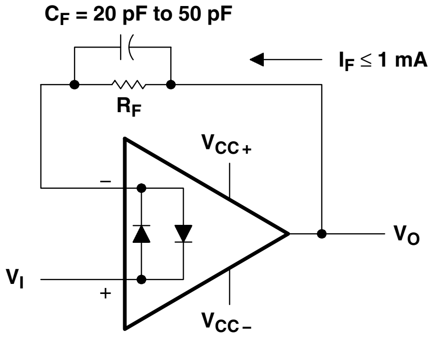

Figure 71. Voltage Follower

### Input offset voltage nulling

The TLE202x series offers external null pins that further reduce the input offset voltage. The circuit in Figure 72 can be connected as shown if this feature is desired. When external nulling is not needed, the null pins may be left disconnected.

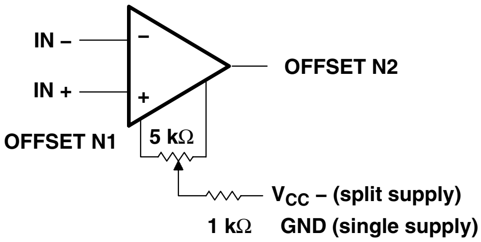

Figure 72. Input Offset Voltage Null Circuit

## APPLICATION INFORMATION

### macromodel information

Macromodel information provided was derived using Microsim *Parts*™, the model generation software used with Microsim *PSpice*™. The Boyle macromodel (see Note 5) and subcircuit in Figure 73, Figure 74, and Figure 75 were generated using the TLE202x typical electrical and operating characteristics at 25°C. Using this information, output simulations of the following key parameters can be generated to a tolerance of 20% (in most cases):

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

NOTE 5: 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).

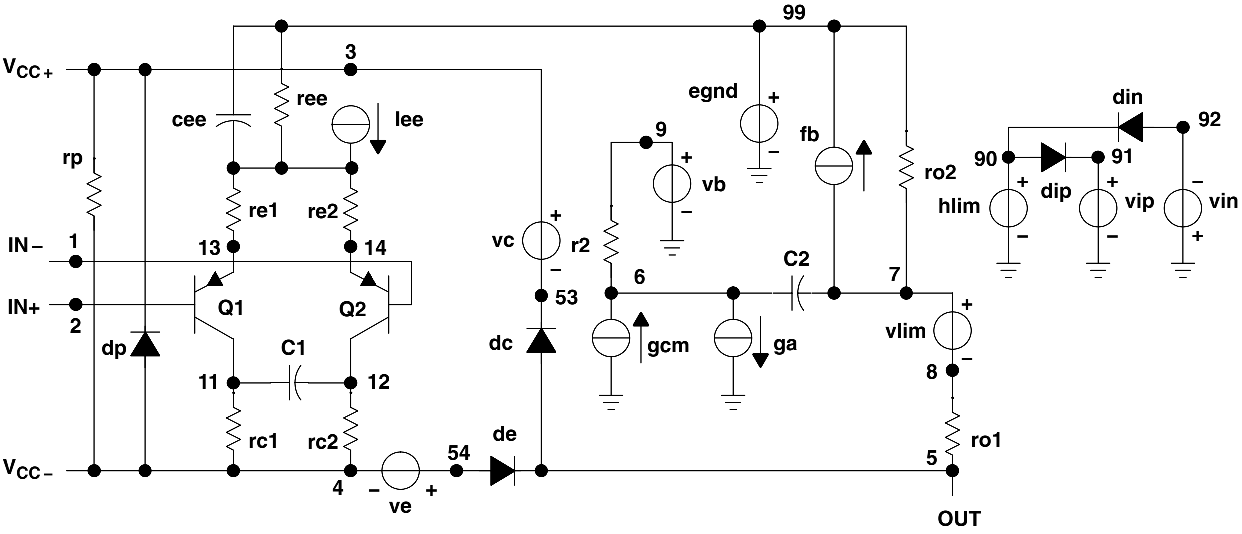

**Figure 73. Boyle Subcircuit**

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

```
.SUBCKT TLE2021  1 2 3 4 5
*
  c1     11   12 6.244E–12
  c2     6    7   13.4E–12
  c3     87   0   10.64E–9
  cpsr   85   86 15.9E–9
  dcm+   81   82 dx
  dcm–   83   81 dx
  dc     5    53 dx
  de     54   5   dx
  dlp    90   91 dx
  dln    92   90 dx
  dp     4    3   dx
  ecmr   84   99 (2 99) 1
  egnd   99   0   poly(2) (3,0) (4,0) 0 .5 .5
  epsr   85   0   poly(1) (3,4) –60E–6  2.0E–6
  ense   89   2   poly(1) (88,0) 120E–6  1
  fb     7    99 poly(6) vb vc ve vlp vln vpsr 0 547.3E6
  + –50E7 50E7 50E7 –50E7 547E6
  ga     6    0   11 12 188.5E–6
  gcm    0    6   10 99 335.2E–12
  gpsr   85   86 (85,86) 100E–6
  grc1   4    11 (4,11) 1.885E–4
  grc2   4    12 (4,12) 1.885E–4
  gre1   13   10 (13,10) 6.82E–4
  gre2   14   10 (14,10) 6.82E–4
  hlim   90   0   vlim 1k
  hcmr  80   1    poly(2) vcm+ vcm– 0 1E2 1E2
  irp   3    4    185E–6
  iee   3    10   dc 15.67E–6
  iio   2    0    2E–9
  i1    88   0    1E–21
  q1    11   89   13 qx
  q2    12   80   14 qx
  R2    6    9    100.0E3
  rcm   84   81   1K
  ree   10   99   14.76E6
  rn1   87   0    2.55E8
  rn2   87   88   11.67E3
  ro1   8    5    62
  ro2   7    99   63
  vcm+  82   99   13.3
  vcm–  83   99   –14.6
  vb    9    0    dc 0
  vc    3    53   dc 1.300
  ve    54   4    dc 1.500
  vlim  7    8    dc 0
  vlp   91   0    dc 3.600
  vln   0    92   dc 3.600
  vpsr  0    86   dc 0
.model dx d(is=800.0E–18)
.model qx pnp(is=800.0E–18 bf=270)
.ends
```

Figure 74. Boyle Macromodel for the TLE2021

```
.SUBCKT TLE2022   1 2 3 4 5
*
  c1    11  12 6.814E-12
  c2    6   7  20.00E-12
  dc    5   53 dx
  de    54  5  dx
  dlp   90  91 dx
  dln   92  90 dx
  dp    4   3  dx
  egnd  99  0  poly(2) (3,0) (4,0) 0 .5 .5
  fb    7   99 poly(5) vb vc ve vlp vln 0
+ 45.47E6 -50E6 50E6 50E6 -50E6
  ga 6  0   11 12 377.9E-6
  gcm 0 6   10 99 7.84E-10
  iee   3   10 DC 18.07E-6
  hlim 90   0  vlim 1k
  q1    11  2  13 qx
  q2    12  1  14 qx
  r2    6   9  100.0E3
  rc1   4   11 2.842E3
  rc2   4   12 2.842E3
  ge1   13  10 (10,13) 31.299E-3
  ge2   14  10 (10,14) 31.299E-3
  ree   10  99 11.07E6
  ro1   8   5  250
  ro2   7   99 250
  rp    3   4  137.2E3
  vb    9   0  dc 0
  vc    3   53 dc 1.300
  ve    54  4  dc 1.500
  vlim 7    8  dc 0
  vlp   91  0  dc 3
  vln   0   92 dc 3
.model dx  d(is=800.0E-18)
.model qx  pnp(is=800.0E-18 bf=257.1)
.ends
```

Figure 75. Boyle Macromodel for the TLE2022

## PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/Ball Finish (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TLE2021AQDRG4Q1 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 2021AQ | Samples |
| TLE2021AQDRQ1 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 2021AQ | Samples |
| TLE2021QDRG4Q1 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 2021Q1 | Samples |
| TLE2021QDRQ1 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 2021Q1 | Samples |
| TLE2022AQDRG4Q1 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 2022AQ | Samples |
| TLE2022AQDRQ1 | OBSOLETE | SOIC | D | 8 |  | TBD | Call TI | Call TI | -40 to 125 |  |  |
| TLE2022QDRG4Q1 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 2022Q1 | Samples |
| TLE2022QDRQ1 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 2022Q1 | Samples |
| TLE2024AQDWRG4Q1 | ACTIVE | SOIC | DW | 16 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 2024AQ1 | Samples |
| TLE2024QDWRG4Q1 | ACTIVE | SOIC | DW | 16 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 2024Q1 | Samples |

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

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
**TBD:** The Pb-Free/Green conversion plan has not been defined.
**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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

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

[6] Lead/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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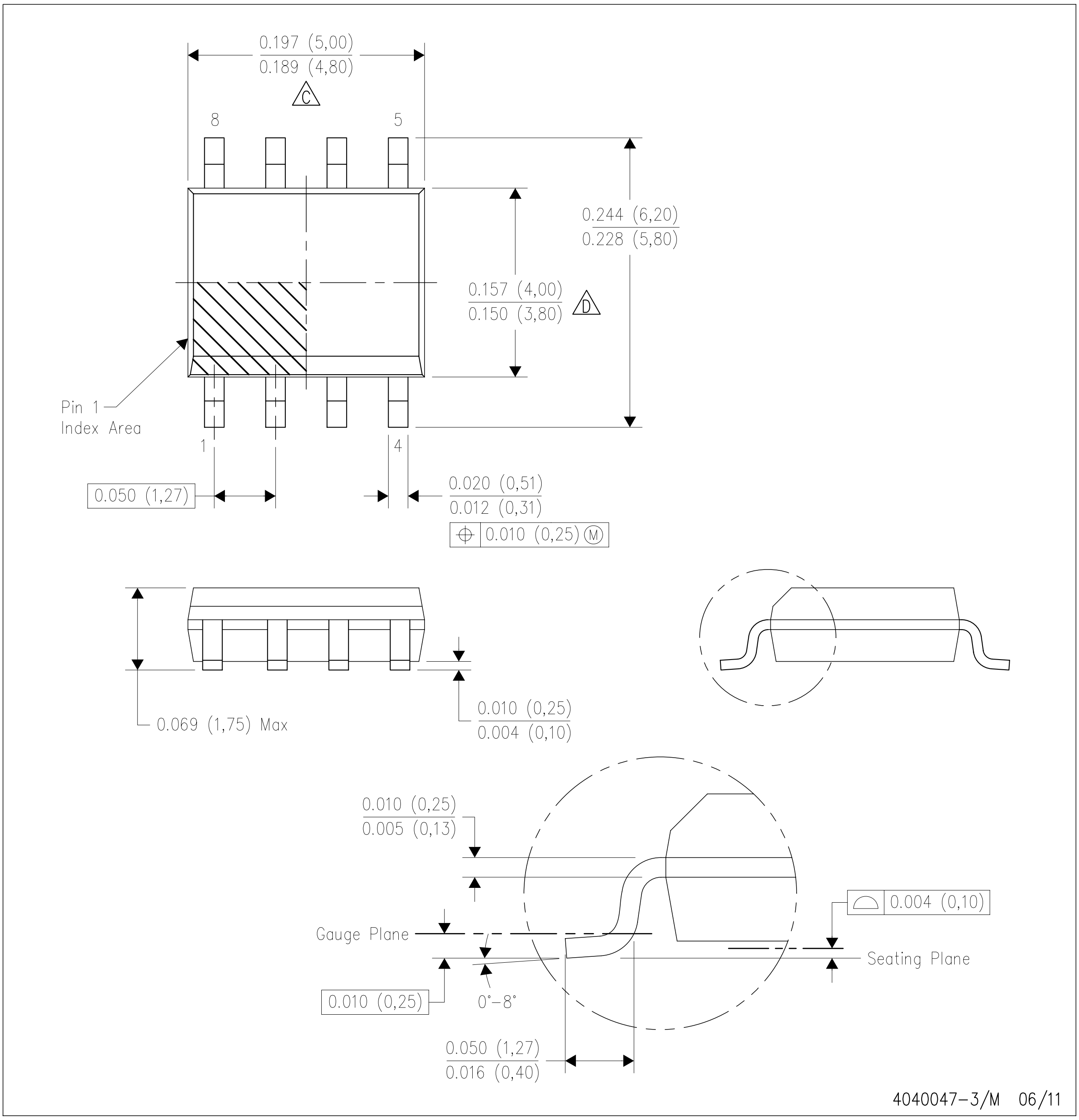
**OTHER QUALIFIED VERSIONS OF TLE2021-Q1, TLE2021A-Q1, TLE2022-Q1, TLE2022A-Q1, TLE2024-Q1, TLE2024A-Q1 :**

- Catalog: TLE2021, TLE2021A, TLE2022, TLE2022A, TLE2024, TLE2024A
- Enhanced Product: TLE2021-EP, TLE2021A-EP, TLE2022-EP, TLE2022A-EP, TLE2024-EP, TLE2024A-EP
- Military: TLE2021M, TLE2021AM, TLE2022M, TLE2022AM, TLE2024M, TLE2024AM

NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product
- Enhanced Product - Supports Defense, Aerospace and Medical Applications
- Military - QML certified for Military and Defense Applications

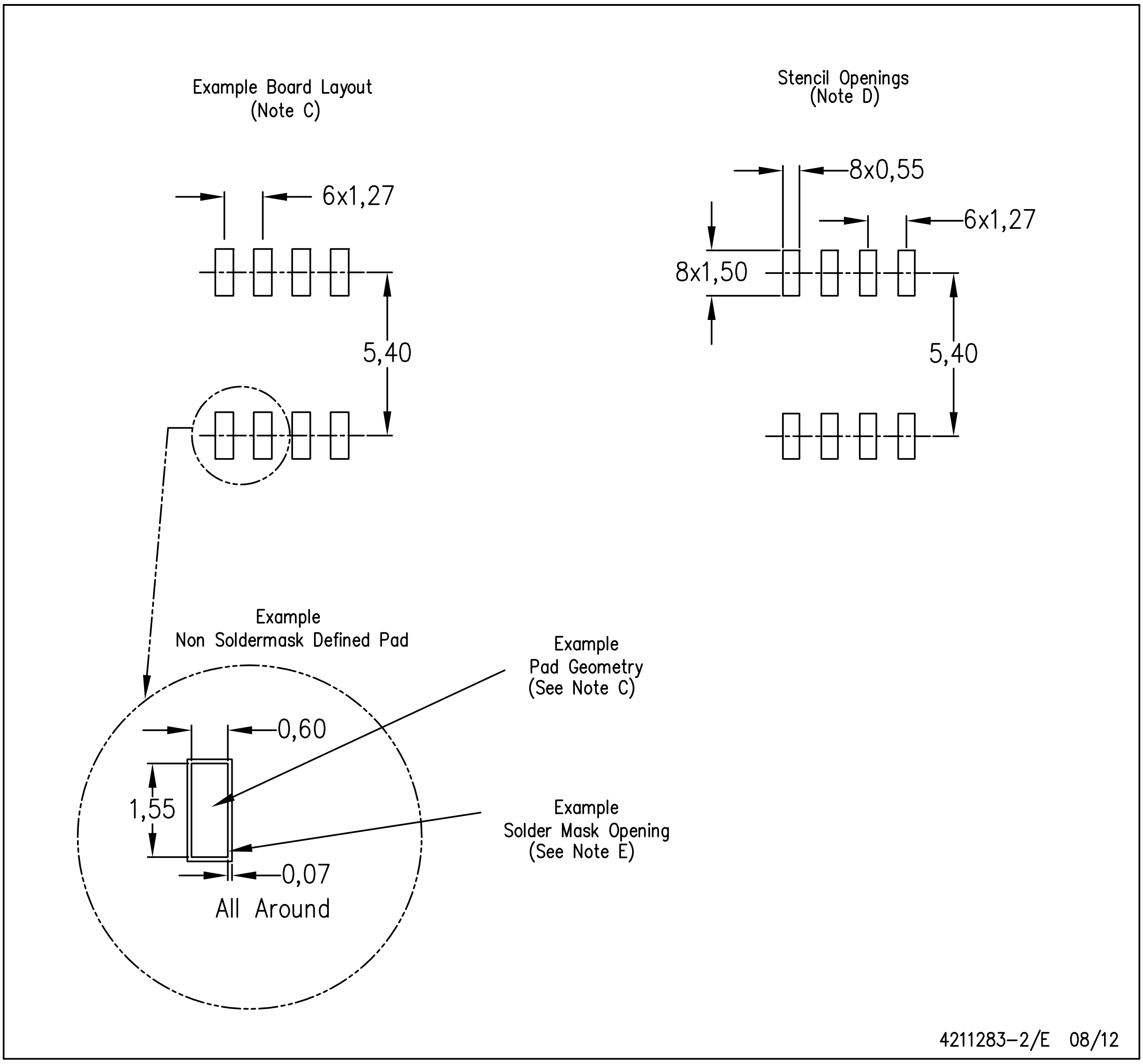
D (R-PDSO-G8) PLASTIC SMALL OUTLINE



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

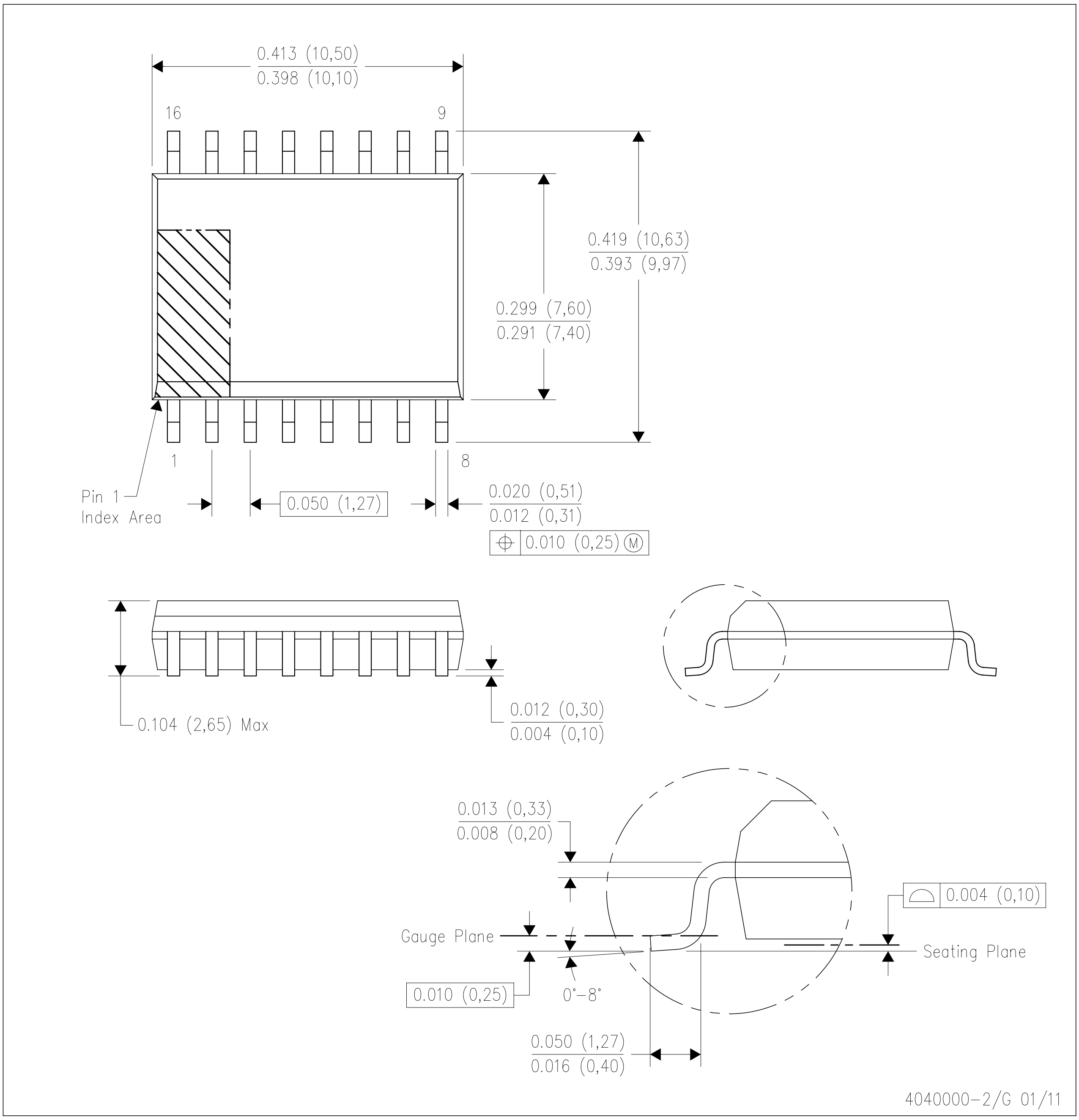
## LAND PATTERN DATA

D (R-PDSO-G8) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC-7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

DW (R-PDSO-G16) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in inches (millimeters). Dimensioning and tolerancing per ASME Y14.5M–1994.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion not to exceed 0.006 (0,15).
- D. Falls within JEDEC MS-013 variation AA.

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