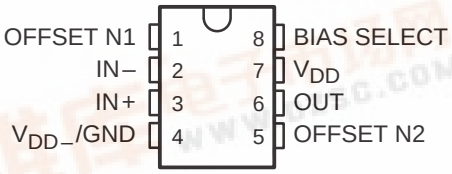
# TLC251C, TLC251AC, TLC251BC, TLC251Y
# LinCMOS™ PROGRAMMABLE LOW-POWER OPERATIONAL AMPLIFIERS

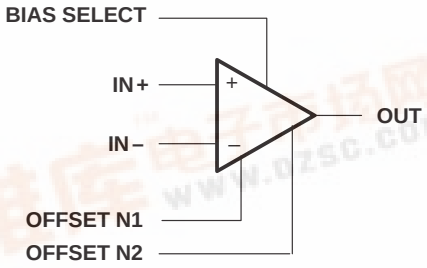
SLOS001E – JULY 1983 – REVISED AUGUST 1994

- **Wide Range of Supply Voltages 1.4 V to 16 V**
- **True Single-Supply Operation**
- **Common-Mode Input Voltage Range Includes the Negative Rail**
- **Low Noise . . . 30 nV/√Hz Typ at 1 kHz (High Bias)**
- **ESD Protection Exceeds 2000 V Per MIL-STD-833C, Method 3015.1**

**D OR P PACKAGE**
**(TOP VIEW)**




## symbol




## description

The TLC251C, TLC251AC, and TLC251BC are low-cost, low-power programmable operational amplifiers designed to operate with single or dual supplies. Unlike traditional metal-gate CMOS operational amplifiers, these devices utilize Texas Instruments silicon-gate LinCMOS™ process, giving them stable input offset voltages without sacrificing the advantages of metal-gate CMOS. This series of parts is available in selected grades of input offset voltage and can be nulled with one external potentiometer. Because the input common-mode range extends to the negative rail and the power consumption is extremely low, this family is ideally suited for battery-powered or energy-conserving applications. A bias-select pin can be used to program one of three ac performance and power-dissipation levels to suit the application. The series features operation down to a 1.4-V supply and is stable at unity gain.

These devices have internal electrostatic-discharge (ESD) protection circuits that prevent catastrophic failures at voltages up to 2000 V as tested under MIL-STD-883C, Method 3015.1. However, care should be exercised in handling these devices as exposure to ESD may result in a degradation of the device parametric performance.

Because of the extremely high input impedance and low input bias and offset currents, applications for the TLC251C series include many areas that have previously been limited to BIFET and NFET product types. Any circuit using high-impedance elements and requiring small offset errors is a good candidate for cost-effective use of these devices. Many features associated with bipolar technology are available with LinCMOS™ operational amplifiers without the power penalties of traditional bipolar devices. Remote and inaccessible equipment applications are possible using the low-voltage and low-power capabilities of the TLC251C series.

In addition, by driving the bias-select input with a logic signal from a microprocessor, these operational amplifiers can have software-controlled performance and power consumption. The TLC251C series is well suited to solve the difficult problems associated with single battery and solar cell-powered applications.

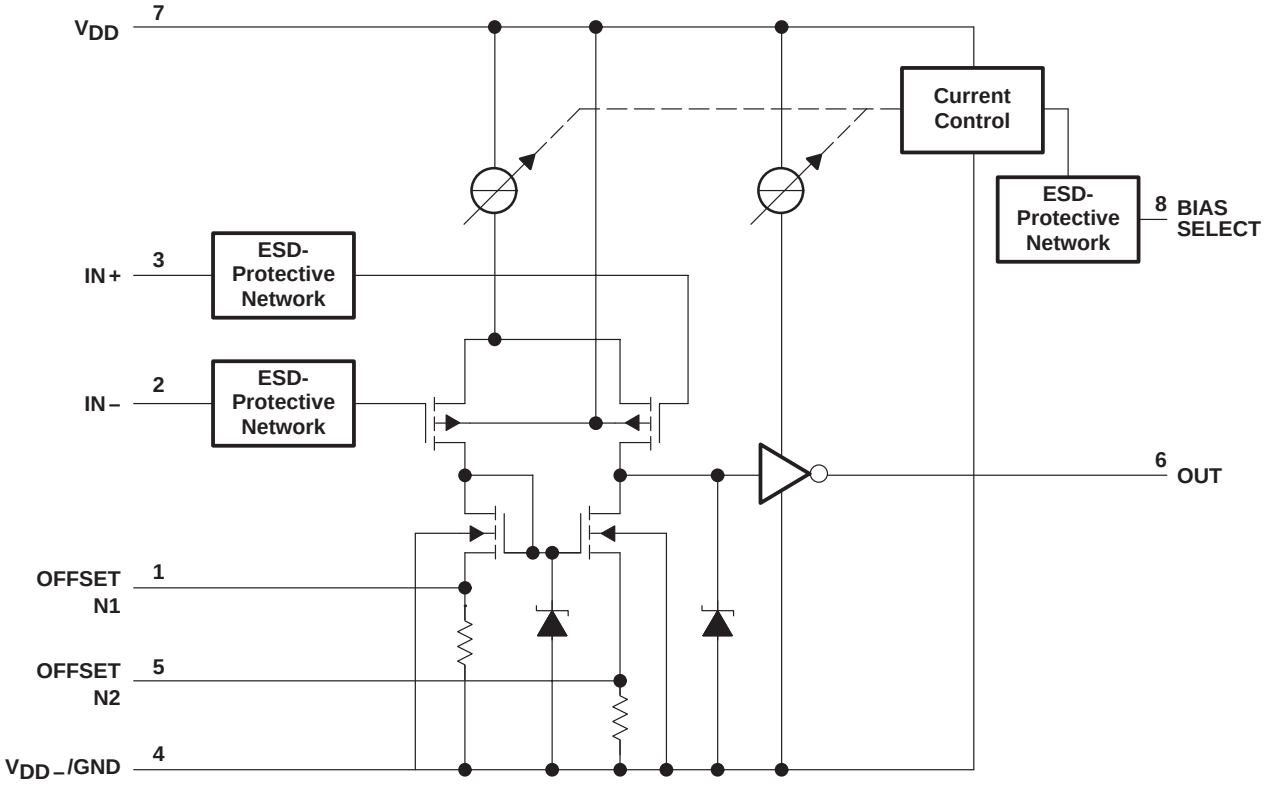
The TLC251C series is characterized for operation from 0°C to 70°C.

**AVAILABLE OPTIONS**

| $T_A$ | $V_{IO}$max AT 25°C | PACKAGED DEVICES | | CHIP FORM (Y) |
|---|---|---|---|---|
| | | SMALL OUTLINE (D) | PLASTIC DIP (P) | |
| 0°C to 70°C | 10 mV | TLC251CD | TLC251CP | TLC251Y |
| | 5 mV | TLC251ACD | TLC251ACP | — |
| | 2 mV | TLC251BCD | TLC251BCP | — |

The D package is available taped and reeled. Add the suffix R to the device type (e.g., TLC251CDR). Chips are tested at 25°C.

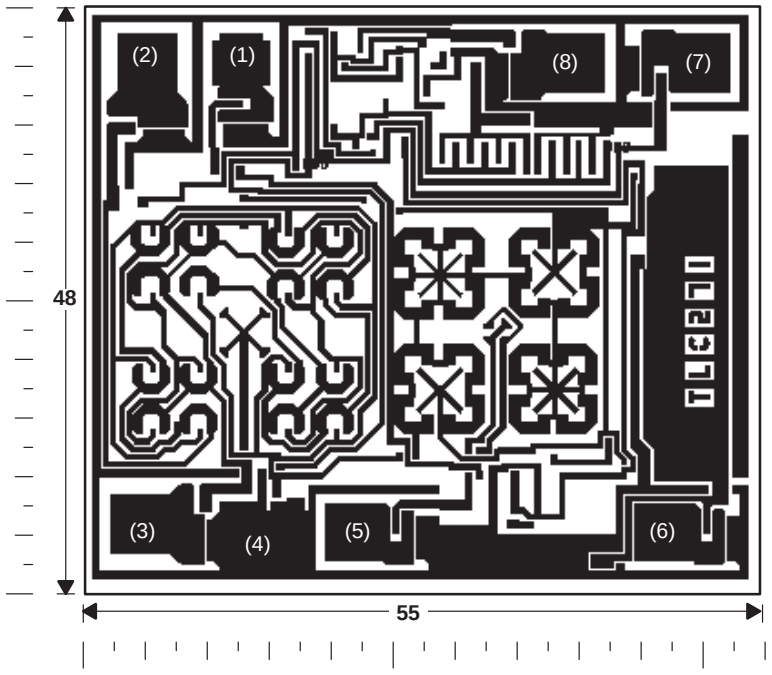
## schematic

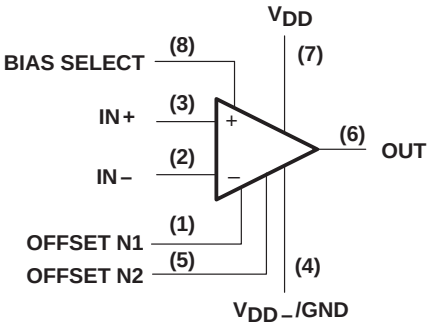

VDD
7
Current Control
ESD-Protective Network
8
BIAS SELECT
IN+
3
ESD-Protective Network
IN–
2
ESD-Protective Network
6
OUT
OFFSET N1
1
OFFSET N2
5
VDD–/GND
4

## TLC251Y chip information

These chips, properly assembled, display characteristics similar to the TLC251C. Thermal compression or ultrasonic bonding may be used on the doped-aluminum bonding pads. Chips may be mounted with conductive epoxy or a gold-silicon preform.

**BONDING PAD ASSIGNMENTS**




**CHIP THICKNESS: 15 TYPICAL**

**BONDING PADS: 4 × 4 MINIMUM**

**$T_{JMAX}$ = 150°C**

**TOLERANCES ARE ±10%.**

**ALL DIMENSIONS ARE IN MILS.**

**PIN (4) IS INTERNALLY CONNECTED TO BACKSIDE OF CHIP.**

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

Supply voltage, $V_{DD}$ (see Note 1) . . . . . 18 V
Differential input voltage, $V_{ID}$ (see Note 2) . . . . . ±18 V
Input voltage range, $V_I$ (any input) . . . . . –0.3 V to 18 V
Duration of short circuit at (or below) 25°C free-air temperature (see Note 3) . . . . . unlimited
Continuous total dissipation . . . . . See Dissipation Rating Table
Operating free-air temperature range, $T_A$ . . . . . 0°C to 70°C
Storage temperature range . . . . . –65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . . 260°C

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

NOTES: 1. All voltage values, except differential voltages, are with respect to $V_{DD-}$/GND.
2. Differential voltages are at IN+ with respect to IN–.
3. The output may be shorted to either supply. Temperature and/or supply voltages must be limited to ensure the maximum dissipation rating is not exceeded.

**DISSIPATION RATING TABLE**

| PACKAGE | $T_A \le 25°C$ POWER RATING | DERATING FACTOR ABOVE $T_A = 25°C$ | $T_A = 70°C$ POWER RATING |
|---|---|---|---|
| D | 725 mW | 5.8 mW/°C | 464 mW |
| P | 1000 mW | 8.0 mW/°C | 640 mW |

## recommended operating conditions

| | | MIN | MAX | UNIT |
|---|---|---|---|---|
| Supply voltage, $V_{DD}$ | | 1.4 | 16 | V |
| Common-mode input voltage, $V_{IC}$ | $V_{DD}$ = 1.4 V | 0 | 0.2 | V |
| | $V_{DD}$ = 5 V | –0.2 | 4 | |
| | $V_{DD}$ = 10 V | –0.2 | 9 | |
| | $V_{DD}$ = 16 V | –0.2 | 14 | |
| Operating free-air temperature, $T_A$ | | 0 | 70 | °C |
| Bias-select voltage | | See Application Information | | |

## HIGH-BIAS MODE

### electrical characteristics at specified free-air temperature

| PARAMETER | | | TEST CONDITIONS | $T_A$† | TLC251C, TLC251AC, TLC251BC | | | | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $V_{DD}$ = 5 V | | | $V_{DD}$ = 10 V | | | |
| | | | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | TLC251C | $V_O$ = 1.4 V, $V_{IC}$ = 0 V, $R_S$ = 50 Ω, $R_L$ = 10 kΩ | 25°C | | 1.1 | 10 | | 1.1 | 10 | mV |
| | | | | Full range | | | 12 | | | 12 | |
| | | TLC251AC | | 25°C | | 0.9 | 5 | | 0.9 | 5 | |
| | | | | Full range | | | 6.5 | | | 6.5 | |
| | | TLC251BC | | 25°C | | 0.34 | 2 | | 0.39 | 2 | |
| | | | | Full range | | | 3 | | | 3 | |
| $\alpha_{VIO}$ | Average temperature coefficient of input offset voltage | | | 25°C to 70°C | | 1.8 | | | 2 | | µV/°C |
| $I_{IO}$ | Input offset current (see Note 4) | | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$ | 25°C | | 0.1 | | | 0.1 | | pA |
| | | | | 70°C | | 7 | 300 | | 7 | 300 | |
| $I_{IB}$ | Input bias current (see Note 4) | | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$ | 25°C | | 0.6 | | | 0.7 | | pA |
| | | | | 70°C | | 40 | 600 | | 50 | 600 | |
| $V_{ICR}$ | Common-mode input voltage range (see Note 5) | | | 25°C | −0.2 to 4 | −0.3 to 4.2 | | −0.2 to 9 | −0.3 to 9.2 | | V |
| | | | | Full range | −0.2 to 3.5 | | | −0.2 to 8.5 | | | V |
| $V_{OH}$ | High-level output voltage | | $V_{ID}$ = 100 mV, $R_L$ = 10 kΩ | 25°C | 3.2 | 3.8 | | 8 | 8.5 | | V |
| | | | | 0°C | 3 | 3.8 | | 7.8 | 8.5 | | |
| | | | | 70°C | 3 | 3.8 | | 7.8 | 8.4 | | |
| $V_{OL}$ | Low-level output voltage | | $V_{ID}$ = −100 mV, $I_{OL}$ = 0 | 25°C | | 0 | 50 | | 0 | 50 | mV |
| | | | | 0°C | | 0 | 50 | | 0 | 50 | |
| | | | | 70°C | | 0 | 50 | | 0 | 50 | |
| $A_{VD}$ | Large-signal differential voltage amplification | | $R_L$ = 10 kΩ, See Note 6 | 25°C | 5 | 23 | | 10 | 36 | | V/mV |
| | | | | 0°C | 4 | 27 | | 7.5 | 42 | | |
| | | | | 70°C | 4 | 20 | | 7.5 | 32 | | |
| CMRR | Common-mode rejection ratio | | $V_{IC} = V_{ICR}$min | 25°C | 65 | 80 | | 65 | 85 | | dB |
| | | | | 0°C | 60 | 84 | | 60 | 88 | | |
| | | | | 70°C | 60 | 85 | | 60 | 88 | | |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$) | | $V_{DD}$ = 5 V to 10 V, $V_O$ = 1.4 V | 25°C | 65 | 95 | | 65 | 95 | | dB |
| | | | | 0°C | 60 | 94 | | 60 | 94 | | |
| | | | | 70°C | 60 | 96 | | 60 | 96 | | |
| $I_{I(SEL)}$ | Input current (BIAS SELECT) | | $V_{I(SEL)}$ = 0 | 25°C | | −1.4 | | | −1.9 | | µA |
| $I_{DD}$ | Supply current | | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$, No load | 25°C | | 675 | 1600 | | 950 | 2000 | µA |
| | | | | 0°C | | 775 | 1800 | | 1125 | 2200 | |
| | | | | 70°C | | 575 | 1300 | | 750 | 1700 | |

† Full range is 0°C to 70°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.
6. At $V_{DD}$ = 5 V, $V_O$ = 0.25 V to 2 V; at $V_{DD}$ = 10 V, $V_O$ = 1 V to 6 V.

## HIGH-BIAS MODE

### operating characteristics, $V_{DD}$ = 5 V

| PARAMETER | | TEST CONDITIONS | | | $T_A$ | TLC251C, TLC251AC, TLC251BC | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MIN | TYP | MAX | |
| SR | Slew rate at unity gain | $R_L$ = 10 kΩ, | $C_L$ = 20 pF | $V_{I(PP)}$ = 1 V | 25°C | | 3.6 | | V/μs |
| | | | | | 0°C | | 4 | | |
| | | | | | 70°C | | 3 | | |
| | | | | $V_{I(PP)}$ = 2.5 V | 25°C | | 2.9 | | |
| | | | | | 0°C | | 3.1 | | |
| | | | | | 70°C | | 2.5 | | |
| $V_n$ | Equivalent input noise voltage | f = 1 kHz, | $R_S$ = 20 Ω | | 25°C | | 25 | | nV/√Hz |
| $B_{OM}$ | Maximum output-swing bandwidth | $V_O = V_{OH}$, | $C_L$ = 20 pF, | $R_L$ = 10 kΩ | 25°C | | 320 | | kHz |
| | | | | | 0°C | | 340 | | |
| | | | | | 70°C | | 260 | | |
| $B_1$ | Unity-gain bandwidth | $V_I$ = 10 mV, | $C_L$ = 20 pF | | 25°C | | 1.7 | | MHz |
| | | | | | 0°C | | 2 | | |
| | | | | | 70°C | | 1.3 | | |
| $\phi_m$ | Phase margin | $V_I$ = 10 mV, | f = $B_1$, | $C_L$ = 20 pF | 25°C | | 46° | | |
| | | | | | 0°C | | 47° | | |
| | | | | | 70°C | | 44° | | |

### operating characteristics, $V_{DD}$ = 10 V

| PARAMETER | | TEST CONDITIONS | | | $T_A$ | TLC251C, TLC251AC, TLC251BC | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MIN | TYP | MAX | |
| SR | Slew rate at unity gain | $R_L$ = 10 kΩ, | $C_L$ = 20 pF | $V_{I(PP)}$ = 1 V | 25°C | | 5.3 | | V/μs |
| | | | | | 0°C | | 5.9 | | |
| | | | | | 70°C | | 4.3 | | |
| | | | | $V_{I(PP)}$ = 5.5 V | 25°C | | 4.6 | | |
| | | | | | 0°C | | 5.1 | | |
| | | | | | 70°C | | 3.8 | | |
| $V_n$ | Equivalent input noise voltage | f = 1 kHz, | $R_S$ = 20 Ω | | 25°C | | 25 | | nV/√Hz |
| $B_{OM}$ | Maximum output-swing bandwidth | $V_O = V_{OH}$, | $C_L$ = 20 pF, | $R_L$ = 10 kΩ | 25°C | | 200 | | kHz |
| | | | | | 0°C | | 220 | | |
| | | | | | 70°C | | 140 | | |
| $B_1$ | Unity-gain bandwidth | $V_I$ = 10 mV, | $C_L$ = 20 pF | | 25°C | | 2.2 | | MHz |
| | | | | | 0°C | | 2.5 | | |
| | | | | | 70°C | | 1.8 | | |
| $\phi_m$ | Phase margin | $V_I$ = 10 mV, | f = $B_1$, | $C_L$ = 20 pF | 25°C | | 49° | | |
| | | | | | 0°C | | 50° | | |
| | | | | | 70°C | | 46° | | |

## MEDIUM-BIAS MODE

### electrical characteristics at specified free-air temperature

| PARAMETER | | | TEST CONDITIONS | $T_A$† | TLC251C, TLC251AC, TLC251BC | | | | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $V_{DD}$ = 5 V | | | $V_{DD}$ = 10 V | | | |
| | | | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | TLC251C | $V_O$ = 1.4 V, $V_{IC}$ = 0 V, $R_S$ = 50 Ω, $R_L$ = 10 kΩ | 25°C | | 1.1 | 10 | | 1.1 | 10 | mV |
| | | | | Full range | | | 12 | | | 12 | |
| | | TLC251AC | | 25°C | | 0.9 | 5 | | 0.9 | 5 | |
| | | | | Full range | | | 6.5 | | | 6.5 | |
| | | TLC251BC | | 25°C | | 0.34 | 2 | | 0.39 | 2 | |
| | | | | Full range | | | 3 | | | 3 | |
| $\alpha_{VIO}$ | Average temperature coefficient of input offset voltage | | | 25°C to 70°C | | 1.7 | | | 2.1 | | µV/°C |
| $I_{IO}$ | Input offset current (see Note 4) | | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$ | 25°C | | 0.1 | | | 0.1 | | pA |
| | | | | 70°C | | 7 | 300 | | 7 | 300 | |
| $I_{IB}$ | Input bias current (see Note 4) | | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$ | 25°C | | 0.6 | | | 0.7 | | pA |
| | | | | 70°C | | 40 | 600 | | 50 | 600 | |
| $V_{ICR}$ | Common-mode input voltage range (see Note 5) | | | 25°C | −0.2 to 4 | −0.3 to 4.2 | | −0.2 to 9 | −0.3 to 9.2 | | V |
| | | | | Full range | −0.2 to 3.5 | | | −0.2 to 8.5 | | | V |
| $V_{OH}$ | High-level output voltage | | $V_{ID}$ = 100 mV, $R_L$ = 10 kΩ | 25°C | 3.2 | 3.9 | | 8 | 8.7 | | V |
| | | | | 0°C | 3 | 3.9 | | 7.8 | 8.7 | | |
| | | | | 70°C | 3 | 4 | | 7.8 | 8.7 | | |
| $V_{OL}$ | Low-level output voltage | | $V_{ID}$ = −100 mV, $I_{OL}$ = 0 | 25°C | | 0 | 50 | | 0 | 50 | mV |
| | | | | 0°C | | 0 | 50 | | 0 | 50 | |
| | | | | 70°C | | 0 | 50 | | 0 | 50 | |
| $A_{VD}$ | Large-signal differential voltage amplification | | $R_L$ = 10 kΩ, See Note 6 | 25°C | 25 | 170 | | 25 | 275 | | V/mV |
| | | | | 0°C | 15 | 200 | | 15 | 320 | | |
| | | | | 70°C | 15 | 140 | | 15 | 230 | | |
| CMRR | Common-mode rejection ratio | | $V_{IC} = V_{ICR}$min | 25°C | 65 | 91 | | 65 | 94 | | dB |
| | | | | 0°C | 60 | 91 | | 60 | 94 | | |
| | | | | 70°C | 60 | 92 | | 60 | 94 | | |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$) | | $V_{DD}$ = 5 V to 10 V, $V_O$ = 1.4 V | 25°C | 70 | 93 | | 70 | 93 | | dB |
| | | | | 0°C | 60 | 92 | | 60 | 92 | | |
| | | | | 70°C | 60 | 94 | | 60 | 94 | | |
| $I_{I(SEL)}$ | Input current (BIAS SELECT) | | $V_{I(SEL)} = V_{DD}/2$ | 25°C | | −130 | | | −160 | | nA |
| $I_{DD}$ | Supply current | | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$, No load | 25°C | | 105 | 280 | | 143 | 300 | µA |
| | | | | 0°C | | 125 | 320 | | 173 | 400 | |
| | | | | 70°C | | 85 | 220 | | 110 | 280 | |

† Full range is 0°C to 70°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.
6. At $V_{DD}$ = 5 V, $V_O$ = 0.25 V to 2 V; at $V_{DD}$ = 10 V, $V_O$ = 1 V to 6 V.

## MEDIUM-BIAS MODE

### operating characteristics, $V_{DD}$ = 5 V

| PARAMETER | | TEST CONDITIONS | | | $T_A$ | TLC251C, TLC251AC, TLC251BC | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MIN | TYP | MAX | |
| SR | Slew rate at unity gain | $R_L$ = 100 kΩ, | $C_L$ = 20 pF | $V_{I(PP)}$ = 1 V | 25°C | | 0.43 | | V/μs |
| | | | | | 0°C | | 0.46 | | |
| | | | | | 70°C | | 0.36 | | |
| | | | | $V_{I(PP)}$ = 2.5 V | 25°C | | 0.40 | | |
| | | | | | 0°C | | 0.43 | | |
| | | | | | 70°C | | 0.34 | | |
| $V_n$ | Equivalent input noise voltage | f = 1 kHz, | $R_S$ = 20 Ω | | 25°C | | 32 | | nV/√Hz |
| $B_{OM}$ | Maximum output-swing bandwidth | $V_O = V_{OH}$, | $C_L$ = 20 pF, | $R_L$ = 100 kΩ | 25°C | | 55 | | kHz |
| | | | | | 0°C | | 60 | | |
| | | | | | 70°C | | 50 | | |
| $B_1$ | Unity-gain bandwidth | $V_I$ = 10 mV, | $C_L$ = 20 pF | | 25°C | | 525 | | kHz |
| | | | | | 0°C | | 600 | | |
| | | | | | 70°C | | 400 | | |
| $\phi_m$ | Phase margin | $V_I$ = 10 mV, | f = $B_1$, | $C_L$ = 20 pF | 25°C | | 40° | | |
| | | | | | 0°C | | 41° | | |
| | | | | | 70°C | | 39° | | |

### operating characteristics, $V_{DD}$ = 10 V

| PARAMETER | | TEST CONDITIONS | | | $T_A$ | TLC251C, TLC251AC, TLC251BC | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MIN | TYP | MAX | |
| SR | Slew rate at unity gain | $R_L$ = 100 kΩ, | $C_L$ = 20 pF | $V_{I(PP)}$ = 1 V | 25°C | | 0.62 | | V/μs |
| | | | | | 0°C | | 0.67 | | |
| | | | | | 70°C | | 0.51 | | |
| | | | | $V_{I(PP)}$ = 5.5 V | 25°C | | 0.56 | | |
| | | | | | 0°C | | 0.61 | | |
| | | | | | 70°C | | 0.46 | | |
| $V_n$ | Equivalent input noise voltage | f = 1 kHz, | $R_S$ = 20 Ω | | 25°C | | 32 | | nV/√Hz |
| $B_{OM}$ | Maximum output-swing bandwidth | $V_O = V_{OH}$, | $C_L$ = 20 pF, | $R_L$ = 100 kΩ | 25°C | | 35 | | kHz |
| | | | | | 0°C | | 40 | | |
| | | | | | 70°C | | 30 | | |
| $B_1$ | Unity-gain bandwidth | $V_I$ = 10 mV, | $C_L$ = 20 pF | | 25°C | | 635 | | kHz |
| | | | | | 0°C | | 710 | | |
| | | | | | 70°C | | 510 | | |
| $\phi_m$ | Phase margin | $V_I$ = 10 mV, | f = $B_1$, | $C_L$ = 20 pF | 25°C | | 43° | | |
| | | | | | 0°C | | 44° | | |
| | | | | | 70°C | | 42° | | |

## LOW-BIAS MODE

### electrical characteristics at specified free-air temperature

| PARAMETER | | | TEST CONDITIONS | $T_A$† | TLC251C, TLC251AC, TLC251BC | | | | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $V_{DD}$ = 5 V | | | $V_{DD}$ = 10 V | | | |
| | | | | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | TLC251C | $V_O$ = 1.4 V, $V_{IC}$ = 0 V, $R_S$ = 50 Ω, $R_L$ = 10 MΩ | 25°C | | 1.1 | 10 | | 1.1 | 10 | mV |
| | | | | Full range | | | 12 | | | 12 | |
| | | TLC251AC | | 25°C | | 0.9 | 5 | | 0.9 | 5 | |
| | | | | Full range | | | 6.5 | | | 6.5 | |
| | | TLC251BC | | 25°C | | 0.24 | 2 | | 0.26 | 2 | |
| | | | | Full range | | | 3 | | | 3 | |
| $\alpha_{VIO}$ | Average temperature coefficient of input offset voltage | | | 25°C to 70°C | | 1.1 | | | 1 | | µV/°C |
| $I_{IO}$ | Input offset current (see Note 4) | | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$ | 25°C | | 0.1 | | | 0.1 | | pA |
| | | | | 70°C | | 7 | 300 | | 7 | 300 | |
| $I_{IB}$ | Input bias current (see Note 4) | | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$ | 25°C | | 0.6 | | | 0.7 | | pA |
| | | | | 70°C | | 40 | 600 | | 50 | 600 | |
| $V_{ICR}$ | Common-mode input voltage range (see Note 5) | | | 25°C | −0.2 to 4 | −0.3 to 4.2 | | −0.2 to 9 | −0.3 to 9.2 | | V |
| | | | | Full range | −0.2 to 3.5 | | | −0.2 to 8.5 | | | V |
| $V_{OH}$ | High-level output voltage | | $V_{ID}$ = 100 mV, $R_L$ = 1 MΩ | 25°C | 3.2 | 4.1 | | 8 | 8.9 | | V |
| | | | | 0°C | 3 | 4.1 | | 7.8 | 8.9 | | |
| | | | | 70°C | 3 | 4.2 | | 7.8 | 8.9 | | |
| $V_{OL}$ | Low-level output voltage | | $V_{ID}$ = −100 mV, $I_{OL}$ = 0 | 25°C | | 0 | 50 | | 0 | 50 | mV |
| | | | | 0°C | | 0 | 50 | | 0 | 50 | |
| | | | | 70°C | | 0 | 50 | | 0 | 50 | |
| $A_{VD}$ | Large-signal differential voltage amplification | | $R_L$ = 1 MΩ, See Note 6 | 25°C | 50 | 520 | | 50 | 870 | | V/mV |
| | | | | 0°C | 50 | 700 | | 50 | 1030 | | |
| | | | | 70°C | 50 | 380 | | 50 | 660 | | |
| CMRR | Common-mode rejection ratio | | $V_{IC} = V_{ICR}$min | 25°C | 65 | 94 | | 65 | 97 | | dB |
| | | | | 0°C | 60 | 95 | | 60 | 97 | | |
| | | | | 70°C | 60 | 95 | | 60 | 97 | | |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$) | | $V_{DD}$ = 5 V to 10 V, $V_O$ = 1.4 V | 25°C | 70 | 97 | | 70 | 97 | | dB |
| | | | | 0°C | 60 | 97 | | 60 | 97 | | |
| | | | | 70°C | 60 | 98 | | 60 | 98 | | |
| $I_{I(SEL)}$ | Input current (BIAS SELECT) | | $V_{I(SEL)} = V_{DD}$ | 25°C | | 65 | | | 95 | | nA |
| $I_{DD}$ | Supply current | | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$, No load | 25°C | | 10 | 17 | | 14 | 23 | µA |
| | | | | 0°C | | 12 | 21 | | 18 | 33 | |
| | | | | 70°C | | 8 | 14 | | 11 | 20 | |

† Full range is 0°C to 70°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.
6. At $V_{DD}$ = 5 V, $V_O$ = 0.25 V to 2 V; at $V_{DD}$ = 10 V, $V_O$ = 1 V to 6 V.

## LOW-BIAS MODE

### operating characteristics, $V_{DD}$ = 5 V

| PARAMETER | | TEST CONDITIONS | | | $T_A$ | TLC251C, TLC251AC, TLC251BC | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MIN | TYP | MAX | |
| SR | Slew rate at unity gain | $R_L$ = 1 MΩ, | $C_L$ = 20 pF | $V_{I(PP)}$ = 1 V | 25°C | | 0.03 | | V/μs |
| | | | | | 0°C | | 0.04 | | |
| | | | | | 70°C | | 0.03 | | |
| | | | | $V_{I(PP)}$ = 2.5 V | 25°C | | 0.03 | | |
| | | | | | 0°C | | 0.03 | | |
| | | | | | 70°C | | 0.02 | | |
| $V_n$ | Equivalent input noise voltage | f = 1 kHz, | $R_S$ = 20 Ω | | 25°C | | 68 | | nV/√Hz |
| $B_{OM}$ | Maximum output-swing bandwidth | $V_O = V_{OH}$, | $C_L$ = 20 pF, | $R_L$ = 1 MΩ | 25°C | | 5 | | kHz |
| | | | | | 0°C | | 6 | | |
| | | | | | 70°C | | 4.5 | | |
| $B_1$ | Unity-gain bandwidth | $V_I$ = 10 mV, | $C_L$ = 20 pF | | 25°C | | 85 | | kHz |
| | | | | | 0°C | | 100 | | |
| | | | | | 70°C | | 65 | | |
| $\phi_m$ | Phase margin | $V_I$ = 10 mV, | f = $B_1$, | $C_L$ = 20 pF | 25°C | | 34° | | |
| | | | | | 0°C | | 36° | | |
| | | | | | 70°C | | 30° | | |

### operating characteristics, $V_{DD}$ = 10 V

| PARAMETER | | TEST CONDITIONS | | | $T_A$ | TLC251C, TLC251AC, TLC251BC | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MIN | TYP | MAX | |
| SR | Slew rate at unity gain | $R_L$ = 1 MΩ, | $C_L$ = 20 pF | $V_{I(PP)}$ = 1 V | 25°C | | 0.05 | | V/μs |
| | | | | | 0°C | | 0.05 | | |
| | | | | | 70°C | | 0.04 | | |
| | | | | $V_{I(PP)}$ = 5.5 V | 25°C | | 0.04 | | |
| | | | | | 0°C | | 0.05 | | |
| | | | | | 70°C | | 0.04 | | |
| $V_n$ | Equivalent input noise voltage | f = 1 kHz, | $R_S$ = 20 Ω | | 25°C | | 68 | | nV/√Hz |
| $B_{OM}$ | Maximum output-swing bandwidth | $V_O = V_{OH}$, | $C_L$ = 20 pF, | $R_L$ = 1 MΩ | 25°C | | 1 | | kHz |
| | | | | | 0°C | | 1.3 | | |
| | | | | | 70°C | | 0.9 | | |
| $B_1$ | Unity-gain bandwidth | $V_I$ = 10 mV, | $C_L$ = 20 pF | | 25°C | | 110 | | kHz |
| | | | | | 0°C | | 125 | | |
| | | | | | 70°C | | 90 | | |
| $\phi_m$ | Phase margin | $V_I$ = 10 mV, | f = $B_1$, | $C_L$ = 20 pF | 25°C | | 38° | | |
| | | | | | 0°C | | 40° | | |
| | | | | | 70°C | | 34° | | |

## electrical characteristics at specified free-air temperature, $V_{DD}$ = 1.4 V

| PARAMETER | | | TEST CONDITIONS† | | $T_A$‡ | BIAS | TLC251C, TLC251AC, TLC251BC | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | TLC251C | $V_O$ = 0.2 V, | $R_S$ = 50 Ω | 25°C | Any | | | 10 | mV |
| | | | | | Full range | | | | 12 | |
| | | TLC251AC | | | 25°C | Any | | | 5 | |
| | | | | | Full range | | | | 6.5 | |
| | | TLC251BC | | | 25°C | Any | | | 2 | |
| | | | | | Full range | | | | 3 | |
| $\alpha_{VIO}$ | Average temperature coefficient of input offset voltage | | | | 25°C to 70°C | Any | | 1 | | µV/°C |
| $I_{IO}$ | Input offset current | | $V_O$ = 0.2 V | | 25°C | Any | | 1 | | pA |
| | | | | | Full range | | | | 300 | |
| $I_{IB}$ | Input bias current | | $V_O$ = 0.2 V | | 25°C | Any | | 1 | | pA |
| | | | | | Full range | | | | 600 | |
| $V_{ICR}$ | Common-mode input voltage range | | | | 25°C | Any | 0 to 0.2 | | | V |
| $V_{OM}$ | Peak output voltage swing§ | | $V_{ID}$ = 100 mV | | 25°C | Any | 450 | 700 | | mV |
| $A_{VD}$ | Large-signal differential voltage amplification | | $V_O$ = 100 to 300 mV, | $R_S$ = 50 Ω | 25°C | Low | | 20 | | |
| | | | | | | High | | 10 | | |
| CMRR | Common-mode rejection ratio | | $R_S$ = 50 Ω, $V_{IC}$ = $V_{ICR}$min | $V_O$ = 0.2 V, | 25°C | Any | 60 | 77 | | dB |
| $I_{DD}$ | Supply current | | $V_O$ = 0.2 V, | No load | 25°C | Low | | 5 | 17 | µA |
| | | | | | | High | | 150 | 190 | |

† All characteristics are measured under open-loop conditions with zero common-mode input voltage unless otherwise specified. Unless otherwise noted, an output load resistor is connected from the output to ground and has the following values: for low bias, $R_L$ = 1 MΩ, for medium bias, $R_L$ = 100 kΩ, and for high bias, $R_L$ = 10 kΩ.
‡ Full range is 0°C to 70°C.
§ The output swings to the potential of $V_{DD-}$/GND.

## operating characteristics, $V_{DD}$ = 1.4 V, $T_A$ = 25°C

| PARAMETER | | TEST CONDITIONS | BIAS | TLC251C, TLC251AC, TLC251BC | | | UNIT |
|---|---|---|---|---|---|---|---|
| | | | | MIN | TYP | MAX | |
| $B_1$ | Unity-gain bandwidth | $C_L$ = 100 pF | Low | | 12 | | kHz |
| | | | High | | 12 | | |
| SR | Slew rate at unity gain | See Figure 1 | Low | | 0.001 | | V/µs |
| | | | High | | 0.1 | | |
| | Overshoot factor | See Figure 1 | Low | | 35% | | |
| | | | High | | 30% | | |

## electrical characteristics, $V_{DD}$ = 5 V, $T_A$ = 25°C

| PARAMETER | | TEST CONDITIONS | TLC251Y | | | | | | | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | HIGH-BIAS MODE | | | MEDIUM-BIAS MODE | | | LOW-BIAS MODE | | | |
| | | | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | $V_O$ = 1.4 V, $V_{IC}$ = 0 V, $R_S$ = 50 Ω, $R_L$† | | 1.1 | 10 | | 1.1 | 10 | | 1.1 | 10 | mV |
| $\alpha_{VIO}$ | Average temperature coefficient of input offset voltage | | | 1.8 | | | 1.7 | | | 1.1 | | μV/°C |
| $I_{IO}$ | Input offset current (see Note 4) | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$ | | 0.1 | | | 0.1 | | | 0.1 | | pA |
| $I_{IB}$ | Input bias current (see Note 4) | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$ | | 0.6 | | | 0.6 | | | 0.6 | | pA |
| $V_{ICR}$ | Common-mode input voltage range (see Note 5) | | −0.2 to 4 | −0.3 to 4.2 | | −0.2 to 4 | −0.3 to 4.2 | | −0.2 to 4 | −0.3 to 4.2 | | V |
| $V_{OH}$ | High-level output voltage | $V_{ID}$ = 100 mV, $R_L$† | 3.2 | 3.8 | | 3.2 | 3.9 | | 3.2 | 4.1 | | V |
| $V_{OL}$ | Low-level output voltage | $V_{ID}$ = −100 mV, $I_{OL}$ = 0 | | 0 | 50 | | 0 | 50 | | 0 | 50 | mV |
| $A_{VD}$ | Large-signal differential voltage amplification | $V_O$ = 0.25 V, $R_L$† | 5 | 23 | | 25 | 170 | | 50 | 480 | | V/mV |
| CMRR | Common-mode rejection ratio | $V_{IC} = V_{ICR}$min | 65 | 80 | | 65 | 91 | | 65 | 94 | | dB |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$) | $V_{DD}$ = 5 V to 10 V, $V_O$ = 1.4 V | 65 | 95 | | 70 | 93 | | 70 | 97 | | dB |
| $I_{I(SEL)}$ | Input current (BIAS SELECT) | $V_{I(SEL)} = V_{DD}/2$ | | −1.4 | | | −0.13 | | | 0.065 | | μA |
| $I_{DD}$ | Supply current | $V_O = V_{DD}/2$, $V_{IC} = V_{DD}/2$, No load | | 675 | 1600 | | 105 | 280 | | 10 | 17 | μA |

† For high-bias mode, $R_L$ = 10 kΩ; for medium-bias mode, $R_L$ = 100 kΩ; and for low-bias mode, $R_L$ = 1 MΩ.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.

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

| PARAMETER | | TEST CONDITIONS | | TLC251Y | | | | | | | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | HIGH-BIAS MODE | | | MEDIUM-BIAS MODE | | | LOW-BIAS MODE | | | |
| | | | | MIN | TYP | MAX | MIN | TYP | MAX | MIN | TYP | MAX | |
| SR | Slew rate at unity gain | $R_L$†, $C_L$ = 20 pF | $V_{I(PP)}$ = 1 V | | 3.6 | | | 0.43 | | | 0.03 | | V/μs |
| | | | $V_{I(PP)}$ = 2.5 V | | 2.9 | | | 0.40 | | | 0.03 | | |
| $V_n$ | Equivalent input noise voltage | f = 1 kHz, | $R_S$ = 20 Ω | | 25 | | | 32 | | | 68 | | nV/√Hz |
| $B_{OM}$ | Maximum output swing bandwidth | $V_O = V_{OH}$, $R_L$ = 10 kΩ | $C_L$ = 20 pF, | | 320 | | | 55 | | | 4.5 | | kHz |
| $B_1$ | Unity-gain bandwidth | $V_I$ = 10 mV, | $C_L$ = 20 pF | | 1700 | | | 525 | | | 65 | | kHz |
| $\phi_m$ | Phase margin | f = $B_1$, $C_L$ = 20 pF | $V_I$ = 10 mV, | | 46° | | | 40° | | | 34° | | |

† For high-bias mode, $R_L$ = 10 kΩ; for medium-bias mode, $R_L$ = 100 kΩ; and for low-bias mode, $R_L$ = 1 MΩ.

## PARAMETER MEASUREMENT INFORMATION

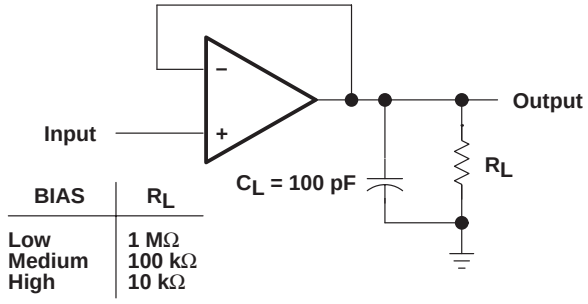



**Figure 1. Unity-Gain Amplifier**

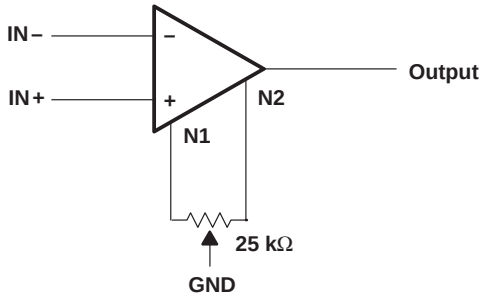



**Figure 2. Input Offset Voltage Null Circuit**

## TYPICAL CHARACTERISTICS

### Table of Graphs

| | | | | FIGURE |
|---|---|---|---|---|
| $I_{DD}$ | Supply current | | vs Bias-select voltage<br>vs Supply voltage<br>vs Free-air temperature | 3<br>4<br>5 |
| $A_{VD}$ | Large-signal differential voltage amplification | Low bias | vs Frequency | 6 |
| | | Medium bias | vs Frequency | 7 |
| | | High bias | vs Frequency | 8 |
| | Phase shift | Low bias | vs Frequency | 6 |
| | | Medium bias | vs Frequency | 7 |
| | | High bias | vs Frequency | 8 |

## TYPICAL CHARACTERISTICS

**SUPPLY CURRENT vs BIAS-SELECT VOLTAGE**

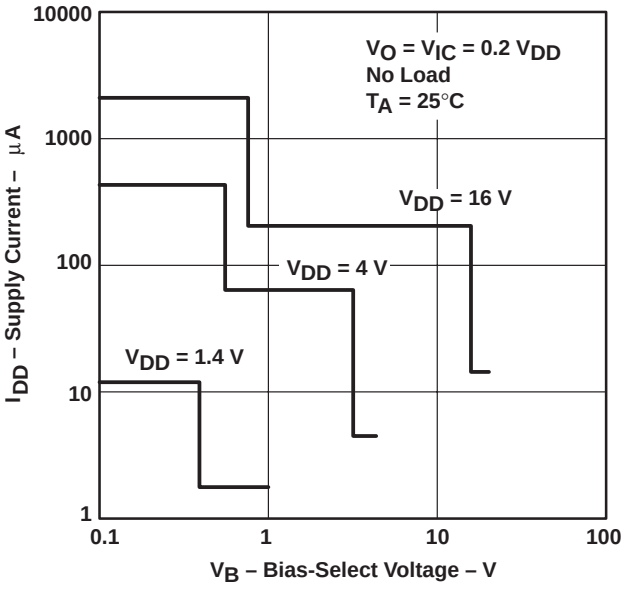



Figure 3

**SUPPLY CURRENT vs SUPPLY VOLTAGE**

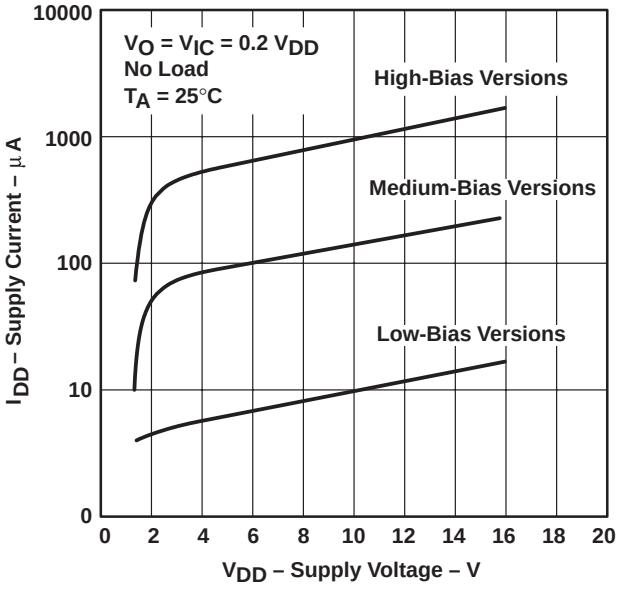



Figure 4

**SUPPLY CURRENT vs FREE-AIR TEMPERATURE**

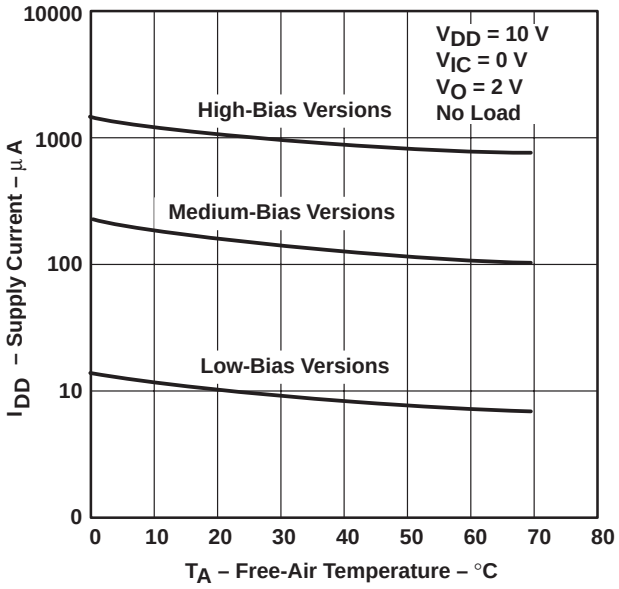



Figure 5

## TYPICAL CHARACTERISTICS

LOW-BIAS LARGE-SIGNAL
DIFFERENTIAL VOLTAGE AMPLIFICATION
AND PHASE SHIFT
vs
FREQUENCY

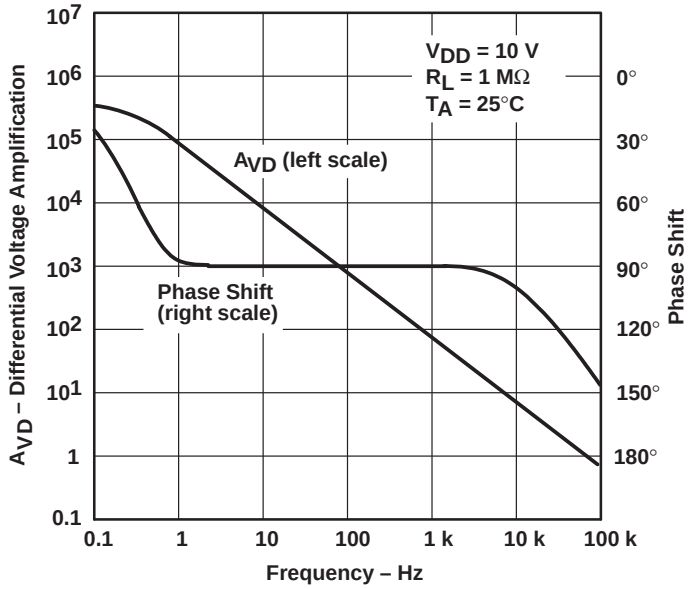



Figure 6

MEDIUM-BIAS LARGE-SIGNAL
DIFFERENTIAL VOLTAGE AMPLIFICATION
AND PHASE SHIFT
vs
FREQUENCY

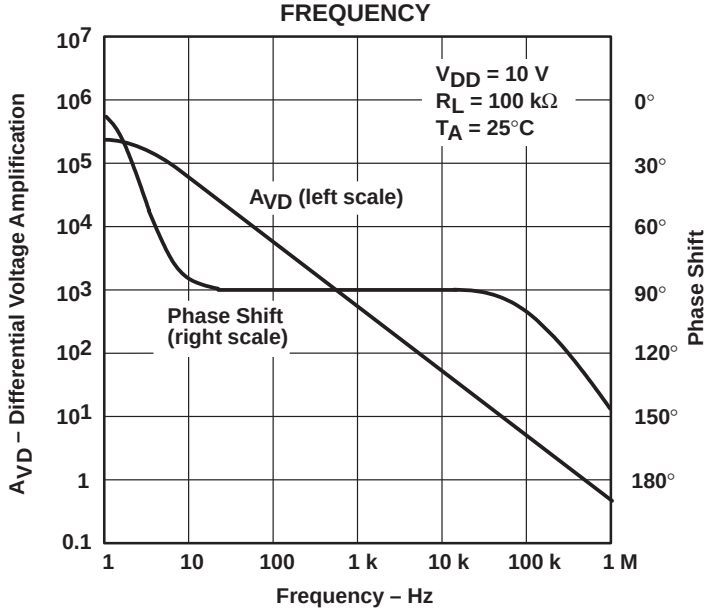



Figure 7

## TYPICAL CHARACTERISTICS

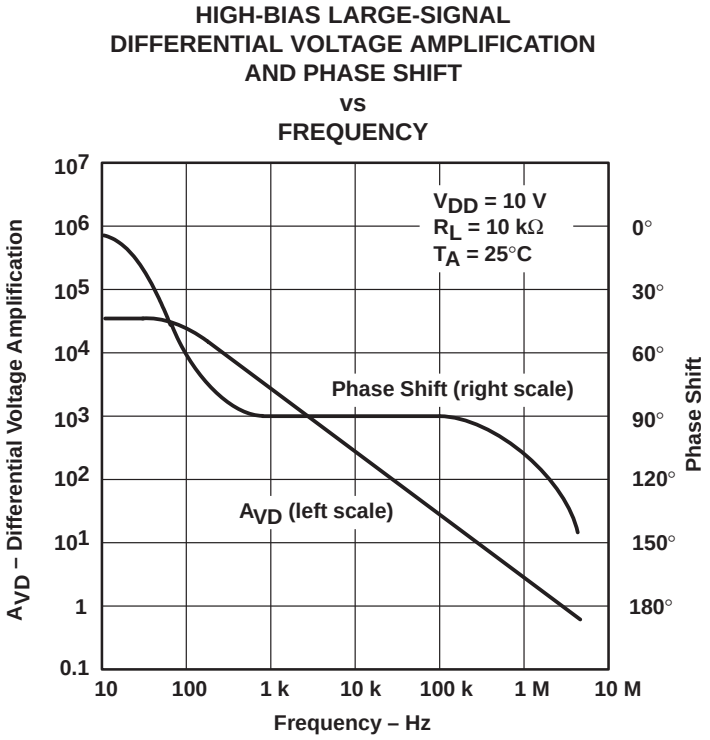



**Figure 8**

## APPLICATION INFORMATION

### latch-up avoidance

Junction-isolated CMOS circuits have an inherent parasitic PNPN structure that can function as an SCR. Under certain conditions, this SCR may be triggered into a low-impedance state, resulting in excessive supply current. To avoid such conditions, no voltage greater than 0.3 V beyond the supply rails should be applied to any pin. In general, the operational amplifier supplies should be applied simultaneously with, or before, application of any input signals.

## APPLICATION INFORMATION

### using BIAS SELECT

The TLC251 has a terminal called BIAS SELECT that allows the selection of one of three $I_{DD}$ conditions (10, 150, and 1000 μA typical). This allows the user to trade-off power and ac performance. As shown in the typical supply current ($I_{DD}$) versus supply voltage ($V_{DD}$) curves (Figure 4), the $I_{DD}$ varies only slightly from 4 V to 16 V. Below 4 V, the $I_{DD}$ varies more significantly. Note that the $I_{DD}$ values in the medium- and low-bias modes at $V_{DD}$ = 1.4 V are typically 2 μA, and in the high mode are typically 12 μA. The following table shows the recommended BIAS SELECT connections at $V_{DD}$ = 10 V.

| BIAS MODE | AC PERFORMANCE | BIAS SELECT CONNECTION† | TYPICAL $I_{DD}$‡ |
|---|---|---|---|
| Low | Low | $V_{DD}$ | 10 μA |
| Medium | Medium | 0.8 V to 9.2 V | 150 μA |
| High | High | Ground pin | 1000 μA |

† Bias selection may also be controlled by external circuitry to conserve power, etc. For information regarding BIAS SELECT, see Figure 3 in the typical characteristics curves.

‡ For $I_{DD}$ characteristics at voltages other than 10 V, see Figure 4 in the typical characteristics curves.

### output stage considerations

The amplifier's output stage consists of a source-follower-connected pullup transistor and an open-drain pulldown transistor. The high-level output voltage ($V_{OH}$) is virtually independent of the $I_{DD}$ selection and increases with higher values of $V_{DD}$ and reduced output loading. The low-level output voltage ($V_{OL}$) decreases with reduced output current and higher input common-mode voltage. With no load, $V_{OL}$ is essentially equal to the potential of $V_{DD-}$/GND.

### input offset nulling

The TLC251C series offers external offset null control. Nulling may be achieved by adjusting a 25-kΩ potentiometer connected between the offset null terminals with the wiper connected to the device $V_{DD-}$/GND pin as shown in Figure 2. The amount of nulling range varies with the bias selection. At an $I_{DD}$ setting of 1000 μA (high bias), the nulling range allows the maximum offset specified to be trimmed to zero. In low or medium bias or when the amplifier is used below 4 V, total nulling may not be possible for all units.

### supply configurations

Even though the TLC251C series is characterized for single-supply operation, it can be used effectively in a split-supply configuration when the input common-mode voltage ($V_{ICR}$), output swing ($V_{OL}$ and $V_{OH}$), and supply voltage limits are not exceeded.

### circuit layout precautions

The user is cautioned that whenever extremely high circuit impedances are used, care must be exercised in layout, construction, board cleanliness, and supply filtering to avoid hum and noise pickup, as well as excessive dc leakages.

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