

# TLC2652, TLC2652A, TLC2652Y

## Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED OPERATIONAL AMPLIFIERS

SLOS019C – SEPTEMBER 1988 – REVISED FEBRUARY 1999

- **Extremely Low Offset Voltage . . . 1  $\mu$ V Max**
- **Extremely Low Change on Offset Voltage With Temperature . . . 0.003  $\mu$ V/ $^{\circ}$ C Typ**
- **Low Input Offset Current**  
500 pA Max at  $T_A = -55^{\circ}\text{C}$  to  $125^{\circ}\text{C}$
- **$A_{VD}$  . . . 135 dB Min**
- **CMRR and  $k_{SVR}$  . . . 120 dB Min**
- **Single-Supply Operation**
- **Common-Mode Input Voltage Range Includes the Negative Rail**
- **No Noise Degradation With External Capacitors Connected to  $V_{DD-}$**

### description

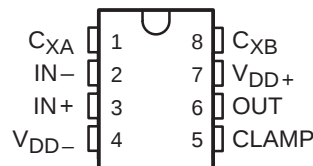
The TLC2652 and TLC2652A are high-precision chopper-stabilized operational amplifiers using Texas Instruments Advanced LinCMOS™ process. This process in conjunction with unique chopper-stabilization circuitry produces operational amplifiers whose performance matches or exceeds that of similar devices available today.

Chopper-stabilization techniques make possible extremely high dc precision by continuously nulling input offset voltage even during variation in temperature, time, common-mode voltage, and power supply voltage. In addition, low-frequency noise voltage is significantly reduced. This high precision, coupled with the extremely high input impedance of the CMOS input stage, makes the TLC2652 and TLC2652A an ideal choice for low-level signal processing applications such as strain gauges, thermocouples, and other transducer amplifiers. For applications that require extremely low noise and higher usable bandwidth, use the TLC2654 or TLC2654A device, which has a chopping frequency of 10 kHz.

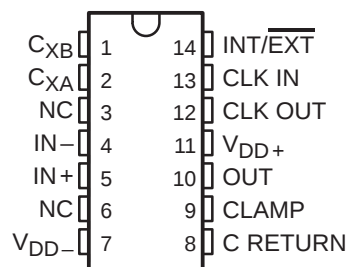
The TLC2652 and TLC2652A input common-mode range includes the negative rail, thereby providing superior performance in either single-supply or split-supply applications, even at power supply voltage levels as low as  $\pm 1.9$  V.

Two external capacitors are required for operation of the device; however, the on-chip chopper-control circuitry is transparent to the user. On devices in the 14-pin and 20-pin packages, the control circuitry is made accessible to allow the user the option of controlling the clock frequency with an external frequency source. In addition, the clock threshold level of the TLC2652 and TLC2652A requires no level shifting when used in the single-supply configuration with a normal CMOS or TTL clock input.

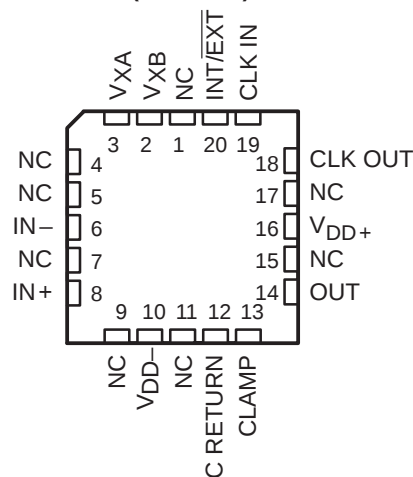
**D008, JG, OR P PACKAGE  
(TOP VIEW)**



**D014, J, OR N PACKAGE  
(TOP VIEW)**



**FK PACKAGE  
(TOP VIEW)**



NC – No internal connection



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PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.



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

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description (continued)

Innovative circuit techniques are used on the TLC2652 and TLC2652A to allow exceptionally fast overload recovery time. If desired, an output clamp pin is available to reduce the recovery time even further.

The device inputs and output are designed to withstand –100-mA surge currents without sustaining latch-up. Additionally the TLC2652 and TLC2652A incorporate internal ESD-protection circuits that prevent functional failures at voltages up to 2000 V as tested under MIL-STD-883C, Method 3015.2; however, care should be exercised in handling these devices as exposure to ESD may result in degradation of the device parametric performance.

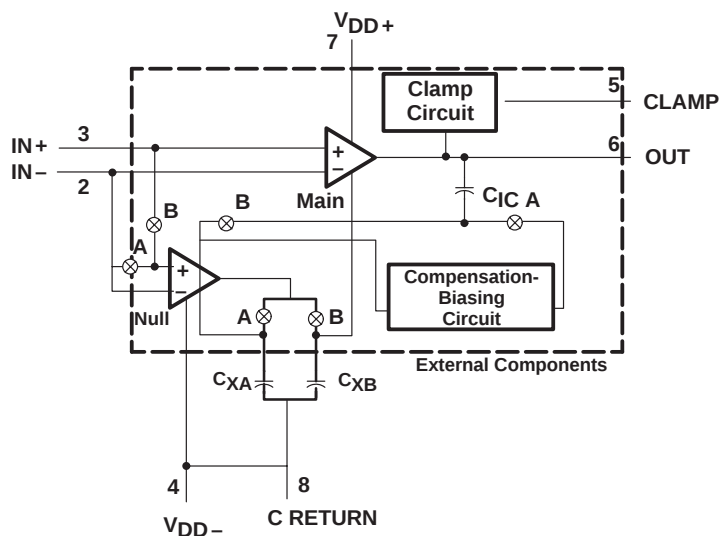
The C-suffix devices are characterized for operation from 0°C to 70°C. The I-suffix devices are characterized for operation from –40°C to 85°C. The Q-suffix devices are characterized for operation from –40°C to 125°C. The M-suffix devices are characterized for operation over the full military temperature range of –55°C to 125°C.

AVAILABLE OPTIONS

| T <sub>A</sub>       | V <sub>IOmax</sub><br>AT 25°C | PACKAGED DEVICES            |                           |                         |                               |                         |                         |                           | CHIP<br>FORM<br>(Y) |
|----------------------|-------------------------------|-----------------------------|---------------------------|-------------------------|-------------------------------|-------------------------|-------------------------|---------------------------|---------------------|
|                      |                               | 8 PIN                       |                           |                         | 14 PIN                        |                         |                         | 20 PIN                    |                     |
|                      |                               | SMALL<br>OUTLINE<br>(D008)  | CERAMIC<br>DIP<br>(JG)    | PLASTIC<br>DIP<br>(P)   | SMALL<br>OUTLINE<br>(D014)    | CERAMIC<br>DIP<br>(J)   | PLASTIC<br>DIP<br>(N)   | CHIP<br>CARRIER<br>(FK)   |                     |
| 0°C<br>to<br>70°C    | 1 µV<br>3 µV                  | TLC2652AC-8D<br>TLC2652C-8D | —<br>—                    | TLC2652ACP<br>TLC2652CP | TLC2652AC-14D<br>TLC2652C-14D | —<br>—                  | TLC2652ACN<br>TLC2652CN | —<br>—                    | TLC2652Y            |
| –40°C<br>to<br>85°C  | 1 µV<br>3 µV                  | TLC2652AI-8D<br>TLC2652A-8D | —<br>—                    | TLC2652AIP<br>TLC2652IP | TLC2652AI-14D<br>TLC2652I-14D | —<br>—                  | TLC2652AIN<br>TLC2652IN | —<br>—                    | —                   |
| –40°C<br>to<br>125°C | 3.5 µV                        | TLC2652Q-8D                 | —                         | —                       | —                             | —                       | —                       | —                         | —                   |
| –55°C<br>to<br>125°C | 3 µV<br>3.5 µV                | TLC2652AM-8D<br>TLC2652M-8D | TLC2652AMJG<br>TLC2652MJG | TLC2652AMP<br>TLC2652MP | TLC2652AM-14D<br>TLC2652M-14D | TLC2652AMJ<br>TLC2652MJ | TLC2652AMN<br>TLC2652MN | TLC2652AMFK<br>TLC2652MFK | —                   |

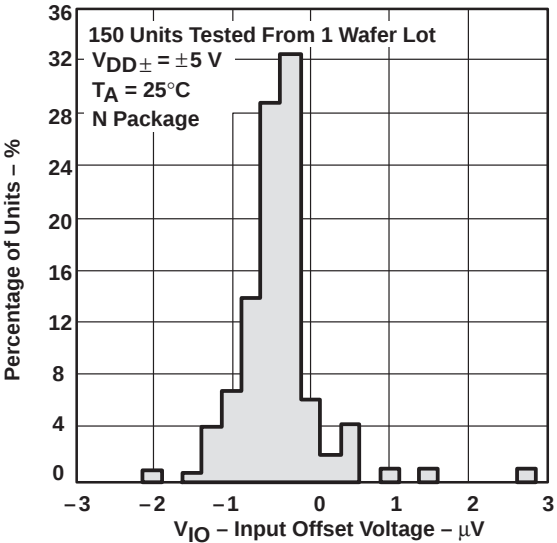
The D008 and D014 packages are available taped and reeled. Add R suffix to the device type (e.g., TLC2652AC-8DR). Chips are tested at 25°C.

functional block diagram



Pin numbers shown are for the D (14 pin), JG, and N packages.

DISTRIBUTION OF TLC2652  
INPUT OFFSET VOLTAGE

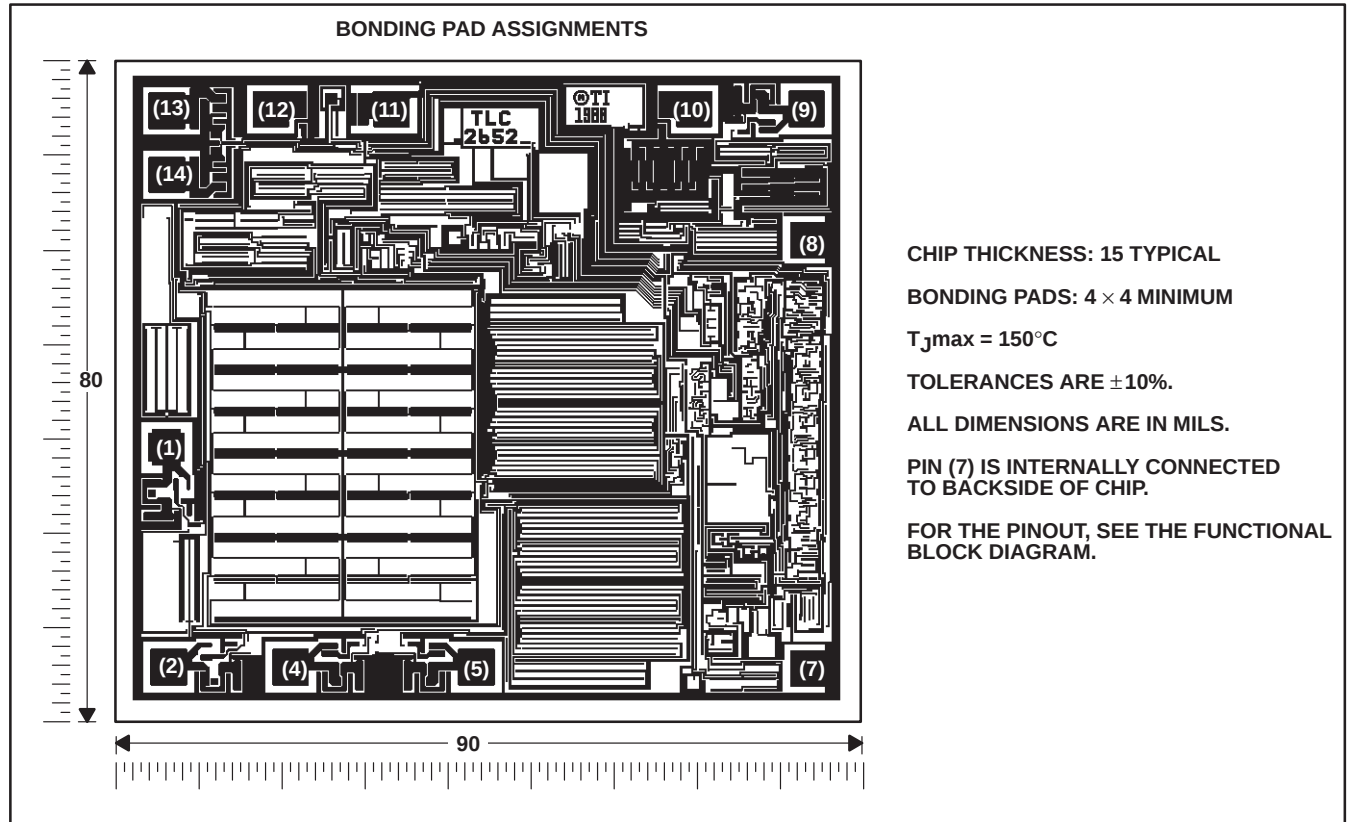


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### TLC2652Y chip information

This chip, when properly assembled, displays characteristics similar to the TLC2652C. 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.



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

|                                                                                  |                                |
|----------------------------------------------------------------------------------|--------------------------------|
| Supply voltage $V_{DD+}$ (see Note 1)                                            | 8 V                            |
| Supply voltage $V_{DD-}$ (see Note 1)                                            | –8 V                           |
| Differential input voltage, $V_{ID}$ (see Note 2)                                | ±16 V                          |
| Input voltage, $V_I$ (any input, see Note 1)                                     | ±8 V                           |
| Voltage range on CLK IN and INT/EXT $\overline{T}$                               | $V_{DD-}$ to $V_{DD-} + 5.2$ V |
| Input current, $I_I$ (each input)                                                | ±5 mA                          |
| Output current, $I_O$                                                            | ±50 mA                         |
| Duration of short-circuit current at (or below) 25°C (see Note 3)                | unlimited                      |
| Current into CLK IN and INT/EXT $\overline{T}$                                   | ±5 mA                          |
| Continuous total dissipation                                                     | See Dissipation Rating Table   |
| Operating free-air temperature range, $T_A$ : C suffix                           | 0°C to 70°C                    |
| I suffix                                                                         | –40°C to 85°C                  |
| Q suffix                                                                         | –40°C to 125°C                 |
| M suffix                                                                         | –55°C to 125°C                 |
| Storage temperature range                                                        | –65°C to 150°C                 |
| Case temperature for 60 seconds: FK package                                      | 260°C                          |
| Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: D, N, or P package | 260°C                          |
| Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds: J or JG package    | 300°C                          |

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

- NOTES: 1. All voltage values, except differential voltages, are with respect to the midpoint between  $V_{DD+}$  and  $V_{DD-}$ .  
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 that the maximum dissipation rating is not exceeded.

DISSIPATION RATING TABLE

| PACKAGE | $T_A \leq 25^\circ\text{C}$<br>POWER RATING | DERATING FACTOR<br>ABOVE $T_A = 25^\circ\text{C}$ | $T_A = 70^\circ\text{C}$<br>POWER RATING | $T_A = 85^\circ\text{C}$<br>POWER RATING | $T_A = 125^\circ\text{C}$<br>POWER RATING |
|---------|---------------------------------------------|---------------------------------------------------|------------------------------------------|------------------------------------------|-------------------------------------------|
| D008    | 725 mW                                      | 5.8 mW/°C                                         | 464 mW                                   | 377 mW                                   | 145 mW                                    |
| D014    | 950 mW                                      | 7.6 mW/°C                                         | 608 mW                                   | 494 mW                                   | 190 mW                                    |
| FK      | 1375 mW                                     | 11.0 mW/°C                                        | 880 mW                                   | 715 mW                                   | 275 mW                                    |
| J       | 1375 mW                                     | 11.0 mW/°C                                        | 880 mW                                   | 715 mW                                   | 275 mW                                    |
| JG      | 1050 mW                                     | 8.4 mW/°C                                         | 672 mW                                   | 546 mW                                   | 210 mW                                    |
| N       | 1575 mW                                     | 12.6 mW/°C                                        | 1008 mW                                  | 819 mW                                   | 315 mW                                    |
| P       | 1000 mW                                     | 8.0 mW/°C                                         | 640 mW                                   | 520 mW                                   | 200 mW                                    |

### recommended operating conditions

|                                       | C SUFFIX  |                 | I SUFFIX  |                 | Q SUFFIX  |                 | M SUFFIX  |                 | UNIT |
|---------------------------------------|-----------|-----------------|-----------|-----------------|-----------|-----------------|-----------|-----------------|------|
|                                       | MIN       | MAX             | MIN       | MAX             | MIN       | MAX             | MIN       | MAX             |      |
| Supply voltage, $V_{DD\pm}$           | ±1.9      | ±8              | ±1.9      | ±8              | ±1.9      | ±8              | ±1.9      | ±8              | V    |
| Common-mode input voltage, $V_{IC}$   | $V_{DD-}$ | $V_{DD+} - 1.9$ | $V_{DD-}$ | $V_{DD+} - 1.9$ | $V_{DD-}$ | $V_{DD+} - 1.9$ | $V_{DD-}$ | $V_{DD+} - 1.9$ | V    |
| Clock input voltage                   | $V_{DD-}$ | $V_{DD-} + 5$   | $V_{DD-}$ | $V_{DD-} + 5$   | $V_{DD-}$ | $V_{DD-} + 5$   | $V_{DD-}$ | $V_{DD-} + 5$   | V    |
| Operating free-air temperature, $T_A$ | 0         | 70              | –40       | 85              | –40       | 125             | –55       | 125             | °C   |



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

| PARAMETER        |                                                                       | TEST CONDITIONS                                                                             | T <sub>A</sub> <sup>†</sup> | TLC2652C  |      |      | TLC2652AC |      |      | UNIT  |
|------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------------------|-----------|------|------|-----------|------|------|-------|
|                  |                                                                       |                                                                                             |                             | MIN       | TYP  | MAX  | MIN       | TYP  | MAX  |       |
| V <sub>IO</sub>  | Input offset voltage                                                  | V <sub>IC</sub> = 0,      R <sub>S</sub> = 50 Ω                                             | 25°C                        | 0.6       |      | 3    | 0.5       |      | 1    | μV    |
|                  |                                                                       |                                                                                             | Full range                  |           |      | 4.35 |           |      | 2.35 |       |
| α <sub>VIO</sub> | Temperature coefficient of input offset voltage                       |                                                                                             | Full range                  | 0.003     |      | 0.03 | 0.003     |      | 0.03 | μV/°C |
|                  | Input offset voltage long-term drift (see Note 4)                     |                                                                                             | 25°C                        | 0.003     |      | 0.06 | 0.003     |      | 0.02 | μV/mo |
| I <sub>IO</sub>  | Input offset current                                                  |                                                                                             | 25°C                        | 2         |      |      | 2         |      |      | pA    |
|                  |                                                                       |                                                                                             | Full range                  |           |      | 100  |           |      | 100  |       |
| I <sub>IB</sub>  | Input bias current                                                    |                                                                                             | 25°C                        | 4         |      |      | 4         |      |      | pA    |
|                  |                                                                       |                                                                                             | Full range                  |           |      | 100  |           |      | 100  |       |
| V <sub>ICR</sub> | Common-mode input voltage range                                       | R <sub>S</sub> = 50 Ω                                                                       | Full range                  | –5 to 3.1 |      |      | –5 to 3.1 |      |      | V     |
| V <sub>OM+</sub> | Maximum positive peak output voltage swing                            | R <sub>L</sub> = 10 kΩ,      See Note 5                                                     | 25°C                        | 4.7       | 4.8  |      | 4.7       | 4.8  |      | V     |
|                  |                                                                       |                                                                                             | Full range                  | 4.7       |      |      | 4.7       |      |      |       |
| V <sub>OM–</sub> | Maximum negative peak output voltage swing                            | R <sub>L</sub> = 10 kΩ,      See Note 5                                                     | 25°C                        | –4.7      | –4.9 |      | –4.7      | –4.9 |      | V     |
|                  |                                                                       |                                                                                             | Full range                  | –4.7      |      |      | –4.7      |      |      |       |
| A <sub>VD</sub>  | Large-signal differential voltage amplification                       | V <sub>O</sub> = ±4 V,      R <sub>L</sub> = 10 kΩ                                          | 25°C                        | 120       | 150  |      | 135       | 150  |      | dB    |
|                  |                                                                       |                                                                                             | Full range                  | 120       |      |      | 130       |      |      |       |
| f <sub>ch</sub>  | Internal chopping frequency                                           |                                                                                             | 25°C                        | 450       |      |      | 450       |      |      | Hz    |
|                  | Clamp on-state current                                                | R <sub>L</sub> = 100 kΩ                                                                     | 25°C                        | 25        |      |      | 25        |      |      | μA    |
|                  |                                                                       |                                                                                             | Full range                  | 25        |      |      | 25        |      |      |       |
|                  | Clamp off-state current                                               | V <sub>O</sub> = –4 V to 4 V                                                                | 25°C                        | 100       |      |      | 100       |      |      | pA    |
|                  |                                                                       |                                                                                             | Full range                  | 100       |      |      | 100       |      |      |       |
| CMRR             | Common-mode rejection ratio                                           | V <sub>O</sub> = 0,      V <sub>IC</sub> = V <sub>ICRmin</sub> ,      R <sub>S</sub> = 50 Ω | 25°C                        | 120       | 140  |      | 120       | 140  |      | dB    |
|                  |                                                                       |                                                                                             | Full range                  | 120       |      |      | 120       |      |      |       |
| k <sub>SVR</sub> | Supply-voltage rejection ratio (ΔV <sub>DD±</sub> /ΔV <sub>IO</sub> ) | V <sub>DD±</sub> = ±1.9 V to ±8 V,      V <sub>O</sub> = 0,      R <sub>S</sub> = 50 Ω      | 25°C                        | 120       | 135  |      | 120       | 135  |      | dB    |
|                  |                                                                       |                                                                                             | Full range                  | 120       |      |      | 120       |      |      |       |
| I <sub>DD</sub>  | Supply current                                                        |                                                                                             | 25°C                        | 1.5       | 2.4  |      | 1.5       | 2.4  |      | mA    |
|                  |                                                                       |                                                                                             | Full range                  |           |      | 2.5  |           |      | 2.5  |       |

$^\dagger$  Full range is 0° to 70°C.

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

5. Output clamp is not connected.



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operating characteristics specified free-air temperature,  $V_{DD\pm} = \pm 5\text{ V}$

| PARAMETER              |                                                | TEST CONDITIONS                                                                | T <sub>A</sub> <sup>†</sup> | TLC2652C |     |     | TLC2652AC |     |     | UNIT   |
|------------------------|------------------------------------------------|--------------------------------------------------------------------------------|-----------------------------|----------|-----|-----|-----------|-----|-----|--------|
|                        |                                                |                                                                                |                             | MIN      | TYP | MAX | MIN       | TYP | MAX |        |
| SR+                    | Positive slew rate at unity gain               | V <sub>O</sub> = ±2.3 V,<br>R <sub>L</sub> = 10 kΩ,<br>C <sub>L</sub> = 100 pF | 25°C                        | 2        | 2.8 |     | 2         | 2.8 |     | V/μs   |
|                        |                                                |                                                                                | Full range                  | 1.5      |     |     | 1.5       |     |     |        |
| SR–                    | Negative slew rate at unity gain               |                                                                                | 25°C                        | 2.3      | 3.1 |     | 2.3       | 3.1 |     | V/μs   |
|                        |                                                |                                                                                | Full range                  | 1.8      |     |     | 1.8       |     |     |        |
| V <sub>n</sub>         | Equivalent input noise voltage<br>(see Note 6) | f = 10 Hz                                                                      | 25°C                        | 94       |     |     | 94 140    |     |     | nV/√Hz |
|                        |                                                | f = 1 kHz                                                                      | 25°C                        | 23       |     |     | 23 35     |     |     |        |
| V <sub>N(PP)</sub>     | Peak-to-peak equivalent input<br>noise voltage | f = 0 to 1 Hz                                                                  | 25°C                        | 0.8      |     |     | 0.8       |     |     | μV     |
|                        |                                                | f = 0 to 10 Hz                                                                 | 25°C                        | 2.8      |     |     | 2.8       |     |     |        |
| I <sub>n</sub>         | Equivalent input noise current                 | f = 10 kHz                                                                     | 25°C                        | 0.004    |     |     | 0.004     |     |     | fA/√Hz |
| Gain-bandwidth product |                                                | f = 10 kHz,<br>R <sub>L</sub> = 10 kΩ,<br>C <sub>L</sub> = 100 pF              | 25°C                        | 1.9      |     |     | 1.9       |     |     | MHz    |
| φ <sub>m</sub>         | Phase margin at unity gain                     | R <sub>L</sub> = 10 kΩ,<br>C <sub>L</sub> = 100 pF                             | 25°C                        | 48°      |     |     | 48°       |     |     |        |

$^\dagger$  Full range is 0° to 70°C.

NOTE 6: This parameter is tested on a sample basis for the TLC2652A. For other test requirements, please contact the factory. This statement has no bearing on testing or nontesting of other parameters.



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

| PARAMETER                   |                                                                       | TEST CONDITIONS                                                                         |  | T <sub>A</sub> <sup>†</sup> | TLC2652I        |      |      | TLC2652AI       |      |      | UNIT  |
|-----------------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------------------------|--|-----------------------------|-----------------|------|------|-----------------|------|------|-------|
|                             |                                                                       |                                                                                         |  |                             | MIN             | TYP  | MAX  | MIN             | TYP  | MAX  |       |
| V <sub>IO</sub>             | Input offset voltage                                                  | V <sub>IC</sub> = 0,      R <sub>S</sub> = 50 Ω                                         |  | 25°C                        | 0.6             |      | 3    | 0.5             |      | 1    | μV    |
|                             | Full range                                                            |                                                                                         |  |                             |                 | 4.95 |      |                 | 2.95 |      |       |
| α <sub>VIO</sub>            | Temperature coefficient of input offset voltage                       |                                                                                         |  | Full range                  | 0.003           |      | 0.03 | 0.003           |      | 0.03 | μV/°C |
|                             | Input offset voltage long-term drift (see Note 4)                     |                                                                                         |  | 25°C                        | 0.003           |      | 0.06 | 0.003           |      | 0.02 | μV/mo |
| I <sub>IO</sub>             | Input offset current                                                  |                                                                                         |  | 25°C                        | 2               |      |      | 2               |      |      | pA    |
|                             |                                                                       |                                                                                         |  | Full range                  |                 |      | 150  |                 |      | 150  |       |
| I <sub>IB</sub>             | Input bias current                                                    |                                                                                         |  | 25°C                        | 4               |      |      | 4               |      |      | pA    |
|                             |                                                                       |                                                                                         |  | Full range                  |                 |      | 150  |                 |      | 150  |       |
| V <sub>ICR</sub>            | Common-mode input voltage range                                       | R <sub>S</sub> = 50 Ω                                                                   |  | Full range                  | –5<br>to<br>3.1 |      |      | –5<br>to<br>3.1 |      | V    |       |
| V <sub>OM+</sub>            | Maximum positive peak output voltage swing                            | R <sub>L</sub> = 10 kΩ,    See Note 5                                                   |  | 25°C                        | 4.7             | 4.8  |      | 4.7             | 4.8  | V    |       |
|                             |                                                                       |                                                                                         |  | Full range                  | 4.7             |      |      | 4.7             |      |      |       |
| V <sub>OM–</sub>            | Maximum negative peak output voltage swing                            | R <sub>L</sub> = 10 kΩ,    See Note 5                                                   |  | 25°C                        | –4.7            | –4.9 |      | –4.7            | –4.9 | V    |       |
|                             |                                                                       |                                                                                         |  | Full range                  | –4.7            |      |      | –4.7            |      |      |       |
| A <sub>VD</sub>             | Large-signal differential voltage amplification                       | V <sub>O</sub> = ±4 V,    R <sub>L</sub> = 10 kΩ                                        |  | 25°C                        | 120             | 150  |      | 135             | 150  | dB   |       |
|                             |                                                                       |                                                                                         |  | Full range                  | 120             |      |      | 125             |      |      |       |
| Internal chopping frequency |                                                                       |                                                                                         |  | 25°C                        | 450             |      |      | 450             |      | Hz   |       |
| Clamp on-state current      |                                                                       | R <sub>L</sub> = 100 kΩ                                                                 |  | 25°C                        | 25              |      |      | 25              |      | μA   |       |
|                             |                                                                       |                                                                                         |  | Full range                  | 25              |      |      | 25              |      |      |       |
| Clamp off-state current     |                                                                       | V <sub>O</sub> = –4 V to 4 V                                                            |  | 25°C                        | 100             |      |      | 100             |      | pA   |       |
|                             |                                                                       |                                                                                         |  | Full range                  | 100             |      |      | 100             |      |      |       |
| CMRR                        | Common-mode rejection ratio                                           | V <sub>O</sub> = 0,<br>V <sub>IC</sub> = V <sub>ICRmin</sub> ,<br>R <sub>S</sub> = 50 Ω |  | 25°C                        | 120             | 140  |      | 120             | 140  | dB   |       |
|                             |                                                                       |                                                                                         |  | Full range                  | 120             |      |      | 120             |      |      |       |
| k <sub>SVR</sub>            | Supply-voltage rejection ratio (ΔV <sub>DD±</sub> /ΔV <sub>IO</sub> ) | V <sub>DD±</sub> = ±1.9 V to ±8 V,<br>V <sub>O</sub> = 0,      R <sub>S</sub> = 50 Ω    |  | 25°C                        | 120             | 135  |      | 120             | 135  | dB   |       |
|                             |                                                                       |                                                                                         |  | Full range                  | 120             |      |      | 120             |      |      |       |
| I <sub>DD</sub>             | Supply current                                                        | V <sub>O</sub> = 0,      No load                                                        |  | 25°C                        | 1.5             | 2.4  |      | 1.5             | 2.4  | mA   |       |
|                             |                                                                       |                                                                                         |  | Full range                  | 2.5             |      |      | 2.5             |      |      |       |

<sup>†</sup> Full range is –40° to 85°C.

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

5. Output clamp is not connected.

# TLC2652, TLC2652A, TLC2652Y

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operating characteristics at specified free-air temperature,  $V_{DD\pm} = \pm 5\text{ V}$

| PARAMETER              |                                                | TEST<br>CONDITIONS                                                             | T <sub>A</sub> <sup>†</sup> | TLC2652I |     |     | TLC2652AI |     |     | UNIT   |
|------------------------|------------------------------------------------|--------------------------------------------------------------------------------|-----------------------------|----------|-----|-----|-----------|-----|-----|--------|
|                        |                                                |                                                                                |                             | MIN      | TYP | MAX | MIN       | TYP | MAX |        |
| SR+                    | Positive slew rate at unity gain               | V <sub>O</sub> = ±2.3 V,<br>R <sub>L</sub> = 10 kΩ,<br>C <sub>L</sub> = 100 pF | 25°C                        | 2        | 2.8 |     | 2         | 2.8 |     | V/μs   |
|                        |                                                |                                                                                | Full range                  | 1.4      |     |     | 1.4       |     |     |        |
| SR–                    | Negative slew rate at unity gain               |                                                                                | 25°C                        | 2.3      | 3.1 |     | 2.3       | 3.1 |     | V/μs   |
|                        |                                                |                                                                                | Full range                  | 1.7      |     |     | 1.7       |     |     |        |
| V <sub>n</sub>         | Equivalent input noise voltage<br>(see Note 6) | f = 10 Hz                                                                      | 25°C                        | 94       |     |     | 94 140    |     |     | nV/√Hz |
|                        |                                                | f = 1 kHz                                                                      | 25°C                        | 23       |     |     | 23 35     |     |     |        |
| V <sub>N(PP)</sub>     | Peak-to-peak equivalent input<br>noise voltage | f = 0 to 1 Hz                                                                  | 25°C                        | 0.8      |     |     | 0.8       |     |     | μV     |
|                        |                                                | f = 0 to 10 Hz                                                                 | 25°C                        | 2.8      |     |     | 2.8       |     |     |        |
| I <sub>n</sub>         | Equivalent input noise current                 | f = 1 kHz                                                                      | 25°C                        | 0.004    |     |     | 0.004     |     |     | pA/√Hz |
| Gain-bandwidth product |                                                | f = 10 kHz,<br>R <sub>L</sub> = 10 kΩ,<br>C <sub>L</sub> = 100 pF              | 25°C                        | 1.9      |     |     | 1.9       |     |     | MHz    |
| φ <sub>m</sub>         | Phase margin at unity gain                     | R <sub>L</sub> = 10 kΩ,<br>C <sub>L</sub> = 100 pF                             | 25°C                        | 48°      |     |     | 48°       |     |     |        |

$^\dagger$  Full range is  $-40^\circ$  to  $85^\circ\text{C}$ .

NOTE 6: This parameter is tested on a sample basis for the TLC2652A. For other test requirements, please contact the factory. This statement has no bearing on testing or nontesting of other parameters.

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**electrical characteristics at specified free-air temperature,  $V_{DD} \pm \pm 5$  V (unless otherwise noted)**

| PARAMETER        |                                                                          | TEST CONDITIONS                                                                         | T <sub>A</sub> <sup>†</sup> | TLC2652Q<br>TLC2652M |                 |       | TLC2652AM       |       |       | UNIT  |
|------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------|----------------------|-----------------|-------|-----------------|-------|-------|-------|
|                  |                                                                          |                                                                                         |                             | MIN                  | TYP             | MAX   | MIN             | TYP   | MAX   |       |
| V <sub>IO</sub>  | Input offset voltage<br>(see Note 7)                                     | V <sub>IC</sub> = 0,      R <sub>S</sub> = 50 Ω                                         | 25°C                        |                      | 0.6             | 3.5   |                 | 0.5   | 3     | μV    |
|                  |                                                                          |                                                                                         | Full range                  |                      |                 | 10    |                 |       | 8     |       |
| αV <sub>IO</sub> | Temperature coefficient of<br>input offset voltage                       |                                                                                         | Full range                  |                      | 0.003           | 0.03* |                 | 0.003 | 0.03* | μV/°C |
|                  | Input offset voltage<br>long-term drift (see Note 4)                     |                                                                                         | 25°C                        |                      | 0.003           | 0.06* |                 | 0.003 | 0.02* | μV/mo |
| I <sub>IO</sub>  | Input offset current                                                     |                                                                                         | 25°C                        |                      | 2               |       |                 | 2     |       | pA    |
|                  |                                                                          |                                                                                         | Full range                  |                      |                 | 500   |                 |       | 500   |       |
| I <sub>IB</sub>  | Input bias current                                                       |                                                                                         | 25°C                        |                      | 4               |       |                 | 4     |       | pA    |
|                  |                                                                          |                                                                                         | Full range                  |                      |                 | 500   |                 |       | 500   |       |
| V <sub>ICR</sub> | Common-mode input<br>voltage range                                       | R <sub>S</sub> = 50 Ω                                                                   | Full range                  |                      | –5<br>to<br>3.1 |       | –5<br>to<br>3.1 |       | V     |       |
| V <sub>OM+</sub> | Maximum positive peak<br>output voltage swing                            | R <sub>L</sub> = 10 kΩ,    See Note 5                                                   | 25°C                        |                      | 4.7             | 4.8   |                 | 4.7   | 4.8   | V     |
|                  |                                                                          |                                                                                         | Full range                  |                      | 4.7             |       |                 | 4.7   |       |       |
| V <sub>OM–</sub> | Maximum negative peak<br>output voltage swing                            | R <sub>L</sub> = 10 kΩ,    See Note 5                                                   | 25°C                        |                      | –4.7            | –4.9  |                 | –4.7  | –4.9  | V     |
|                  |                                                                          |                                                                                         | Full range                  |                      | –4.7            |       |                 | –4.7  |       |       |
| A <sub>VD</sub>  | Large-signal differential<br>voltage amplification                       | V <sub>O</sub> = ±4 V,    R <sub>L</sub> = 10 kΩ                                        | 25°C                        |                      | 120             | 150   |                 | 135   | 150   | dB    |
|                  |                                                                          |                                                                                         | Full range                  |                      | 120             |       |                 | 120   |       |       |
| f <sub>ch</sub>  | Internal chopping frequency                                              |                                                                                         | 25°C                        |                      | 450             |       | 450             |       | Hz    |       |
|                  | Clamp on-state current                                                   | V <sub>O</sub> = –5 V to 5 V                                                            | 25°C                        |                      | 25              |       | 25              |       | μA    |       |
|                  |                                                                          |                                                                                         | Full range                  |                      | 25              |       | 25              |       |       |       |
|                  | Clamp off-state current                                                  | R <sub>L</sub> = 100 kΩ                                                                 | 25°C                        |                      | 100             |       | 100             |       | pA    |       |
|                  |                                                                          |                                                                                         | Full range                  |                      | 500             |       | 500             |       |       |       |
| CMRR             | Common-mode rejection<br>ratio                                           | V <sub>O</sub> = 0,<br>V <sub>IC</sub> = V <sub>ICRmin</sub> ,<br>R <sub>S</sub> = 50 Ω | 25°C                        |                      | 120             | 140   |                 | 120   | 140   | dB    |
|                  |                                                                          |                                                                                         | Full range                  |                      | 120             |       |                 | 120   |       |       |
| k <sub>SVR</sub> | Supply-voltage rejection<br>ratio (ΔV <sub>DD±</sub> /ΔV <sub>IO</sub> ) | V <sub>DD±</sub> = ±1.9 V to ±8 V,<br>V <sub>O</sub> = 0,      R <sub>S</sub> = 50 Ω    | 25°C                        |                      | 120             | 135   |                 | 120   | 135   | dB    |
|                  |                                                                          |                                                                                         | Full range                  |                      | 120             |       |                 | 120   |       |       |
| I <sub>DD</sub>  | Supply current                                                           | V <sub>O</sub> = 0,      No load                                                        | 25°C                        |                      | 1.5             | 2.4   |                 | 1.5   | 2.4   | mA    |
|                  |                                                                          |                                                                                         | Full range                  |                      |                 | 2.5   |                 |       | 2.5   |       |

\* On products compliant to MIL-PRF-38535, this parameter is not production tested.

$^\dagger$  Full range is  $-40^\circ$  to  $125^\circ C$  for Q suffix,  $-55^\circ$  to  $125^\circ C$  for M suffix.

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

5. Output clamp is not connected.

7. This parameter is not production tested. Thermocouple effects preclude measurement of the actual  $V_{IO}$  of these devices in high speed automated testing.  $V_{IO}$  is measured to a limit determined by the test equipment capability at the temperature extremes. The test ensures that the stabilization circuitry is performing properly.

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**operating characteristics specified free-air temperature,  $V_{DD\pm} = \pm 5\text{ V}$**

| PARAMETER              |                                             | TEST CONDITIONS                                                                | T <sub>A</sub> <sup>†</sup> | TLC2652Q<br>TLC2652M<br>TLC2652AM |     |        | UNIT |
|------------------------|---------------------------------------------|--------------------------------------------------------------------------------|-----------------------------|-----------------------------------|-----|--------|------|
|                        |                                             |                                                                                |                             | MIN                               | TYP | MAX    |      |
| SR +                   | Positive slew rate at unity gain            | V <sub>O</sub> = ±2.3 V,<br>R <sub>L</sub> = 10 kΩ,<br>C <sub>L</sub> = 100 pF | 25°C                        | 2                                 | 2.8 | V/μs   |      |
|                        |                                             |                                                                                | Full range                  | 1.3                               |     |        |      |
| SR –                   | Negative slew rate at unity gain            |                                                                                | 25°C                        | 2.3                               | 3.1 | V/μs   |      |
|                        |                                             |                                                                                | Full range                  | 1.6                               |     |        |      |
| V <sub>n</sub>         | Equivalent input noise voltage              | f = 10 Hz                                                                      | 25°C                        | 94                                |     | nV/√Hz |      |
|                        |                                             | f = 1 kHz                                                                      | 25°C                        | 23                                |     |        |      |
| V <sub>N(PP)</sub>     | Peak-to-peak equivalent input noise voltage | f = 0 to 1 Hz                                                                  | 25°C                        | 0.8                               |     | μV     |      |
|                        |                                             | f = 0 to 10 Hz                                                                 | 25°C                        | 2.8                               |     |        |      |
| I <sub>n</sub>         | Equivalent input noise current              | f = 1 kHz                                                                      | 25°C                        | 0.004                             |     | pA/√Hz |      |
| Gain-bandwidth product |                                             | f = 10 kHz,<br>R <sub>L</sub> = 10 kΩ,<br>C <sub>L</sub> = 100 pF              | 25°C                        | 1.9                               |     | MHz    |      |
| φ <sub>m</sub>         | Phase margin at unity gain                  | R <sub>L</sub> = 10 kΩ,<br>C <sub>L</sub> = 100 pF                             | 25°C                        | 48°                               |     |        |      |

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

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**electrical characteristics at  $V_{DD\pm} = \pm 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$  (unless otherwise noted)**

| PARAMETER |                                                                     | TEST CONDITIONS                                                                    | TLC2652Y        |       |       | UNIT                    |
|-----------|---------------------------------------------------------------------|------------------------------------------------------------------------------------|-----------------|-------|-------|-------------------------|
|           |                                                                     |                                                                                    | MIN             | TYP   | MAX   |                         |
| $V_{IO}$  | Input offset voltage                                                | $V_{IC} = 0$ , $R_S = 50\ \Omega$                                                  |                 | 0.6   | 3     | $\mu\text{V}$           |
|           | Input offset voltage long-term drift (see Note 4)                   |                                                                                    |                 | 0.003 | 0.006 | $\mu\text{V}/\text{mo}$ |
| $I_{IO}$  | Input offset current                                                |                                                                                    |                 | 2     |       | $\text{pA}$             |
| $I_{IB}$  | Input bias current                                                  |                                                                                    |                 | 4     |       | $\text{pA}$             |
| $V_{ICR}$ | Common-mode input voltage range                                     | $R_S = 50\ \Omega$                                                                 | –5<br>to<br>3.1 |       |       | $\text{V}$              |
| $V_{OM+}$ | Maximum positive peak output voltage swing                          | $R_L = 10\ \text{k}\Omega$ , See Note 5                                            | 4.7             | 4.8   |       | $\text{V}$              |
| $V_{OM-}$ | Maximum negative peak output voltage swing                          | $R_L = 10\ \text{k}\Omega$ , See Note 5                                            | –4.7            | –4.9  |       | $\text{V}$              |
| $A_{VD}$  | Large-signal differential voltage amplification                     | $V_O = \pm 4\text{ V}$ , $R_L = 10\ \text{k}\Omega$                                | 120             | 150   |       | $\text{dB}$             |
| $f_{ch}$  | Internal chopping frequency                                         |                                                                                    |                 | 450   |       | $\text{Hz}$             |
|           | Clamp on-state current                                              | $R_L = 100\ \text{k}\Omega$                                                        | 25              |       |       | $\mu\text{A}$           |
|           | Clamp off-state current                                             | $V_O = -4\text{ V to } 4\text{ V}$                                                 |                 |       | 100   | $\text{pA}$             |
| CMRR      | Common-mode rejection ratio                                         | $V_O = 0$ , $R_S = 50\ \Omega$ , $V_{IC} = V_{ICRmin}$                             | 120             | 140   |       | $\text{dB}$             |
| $k_{SVR}$ | Supply-voltage rejection ratio ( $\Delta V_{DD\pm}/\Delta V_{IO}$ ) | $V_{DD\pm} = \pm 1.9\text{ V to } \pm 8\text{ V}$ , $R_S = 50\ \Omega$ , $V_O = 0$ | 120             | 135   |       | $\text{dB}$             |
| $I_{DD}$  | Supply current                                                      | $V_O = 0$ , No load                                                                |                 | 1.5   | 2.4   | $\text{mA}$             |

NOTES: 4. Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at  $T_A = 150^\circ\text{C}$  extrapolated at  $T_A = 25^\circ$  using the Arrhenius equation and assuming an activation energy of 0.96 eV.  
5. Output clamp is not connected.

**operating characteristics at  $V_{DD\pm} = \pm 5\text{ V}$ ,  $T_A = 25^\circ\text{C}$**

| PARAMETER   |                                             | TEST CONDITIONS                                                                | TLC2652Y |     |     | UNIT                         |
|-------------|---------------------------------------------|--------------------------------------------------------------------------------|----------|-----|-----|------------------------------|
|             |                                             |                                                                                | MIN      | TYP | MAX |                              |
| SR+         | Positive slew rate at unity gain            | $V_O = \pm 2.3\text{ V}$ , $R_L = 10\ \text{k}\Omega$ , $C_L = 100\ \text{pF}$ | 2        | 2.8 |     | $\text{V}/\mu\text{s}$       |
| SR–         | Negative slew rate at unity gain            |                                                                                | 2.3      | 3.1 |     | $\text{V}/\mu\text{s}$       |
| $V_n$       | Equivalent input noise voltage              | $f = 10\ \text{Hz}$                                                            |          | 94  |     | $\text{nV}/\sqrt{\text{Hz}}$ |
|             |                                             | $f = 1\ \text{kHz}$                                                            |          | 23  |     |                              |
| $V_{N(PP)}$ | Peak-to-peak equivalent input noise voltage | $f = 0\text{ to } 1\ \text{Hz}$                                                |          | 0.8 |     | $\mu\text{V}$                |
|             |                                             | $f = 0\text{ to } 10\ \text{Hz}$                                               |          | 2.8 |     |                              |
| $I_n$       | Equivalent input noise current              | $f = 1\ \text{kHz}$                                                            |          |     |     | $\text{pA}/\sqrt{\text{Hz}}$ |
|             | Gain-bandwidth product                      | $f = 10\ \text{kHz}$ , $R_L = 10\ \text{k}\Omega$ , $C_L = 100\ \text{pF}$     |          | 1.9 |     | $\text{MHz}$                 |
| $\phi_m$    | Phase margin at unity gain                  | $R_L = 10\ \text{k}\Omega$ , $C_L = 100\ \text{pF}$                            |          | 48° |     |                              |



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**TYPICAL CHARACTERISTICS**

**Table of Graphs**

|             |                                                 |                              | <b>FIGURE</b> |
|-------------|-------------------------------------------------|------------------------------|---------------|
| $V_{IO}$    | Normalized input offset voltage                 | vs Chopping frequency        | 1             |
| $I_{IB}$    | Input bias current                              | vs Common-mode input voltage | 2             |
|             |                                                 | vs Chopping frequency        | 3             |
|             |                                                 | vs Free-air temperature      | 4             |
| $I_{IO}$    | Input offset current                            | vs Chopping frequency        | 5             |
|             |                                                 | vs Free-air temperature      | 6             |
|             | Clamp current                                   | vs Output voltage            | 7             |
| $V_{(OPP)}$ | Maximum peak-to-peak output voltage             | vs Frequency                 | 8             |
| $V_{OM}$    | Maximum peak output voltage                     | vs Output current            | 9, 10         |
|             |                                                 | vs Free-air temperature      | 11, 12        |
| $A_{VD}$    | Large-signal differential voltage amplification | vs Frequency                 | 13            |
|             |                                                 | vs Free-air temperature      | 14            |
|             | Chopping frequency                              | vs Supply voltage            | 15            |
|             |                                                 | vs Free-air temperature      | 16            |
| $I_{DD}$    | Supply current                                  | vs Supply voltage            | 17            |
|             |                                                 | vs Free-air temperature      | 18            |
| $I_{OS}$    | Short-circuit output current                    | vs Supply voltage            | 19            |
|             |                                                 | vs Free-air temperature      | 20            |
| SR          | Slew rate                                       | vs Supply voltage            | 21            |
|             |                                                 | vs Free-air temperature      | 22            |
|             | Pulse response                                  | Small-signal                 | 23            |
|             |                                                 | Large-signal                 | 24            |
| $V_{N(PP)}$ | Peak-to-peak equivalent input noise voltage     | vs Chopping frequency        | 25, 26        |
| $V_n$       | Equivalent input noise voltage                  | vs Frequency                 | 27            |
|             | Gain-bandwidth product                          | vs Supply voltage            | 28            |
|             |                                                 | vs Free-air temperature      | 29            |
| $\phi_m$    | Phase margin                                    | vs Supply voltage            | 30            |
|             |                                                 | vs Free-air temperature      | 31            |
|             |                                                 | vs Load capacitance          | 32            |
|             | Phase shift                                     | vs Frequency                 | 13            |



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## TYPICAL CHARACTERISTICS†

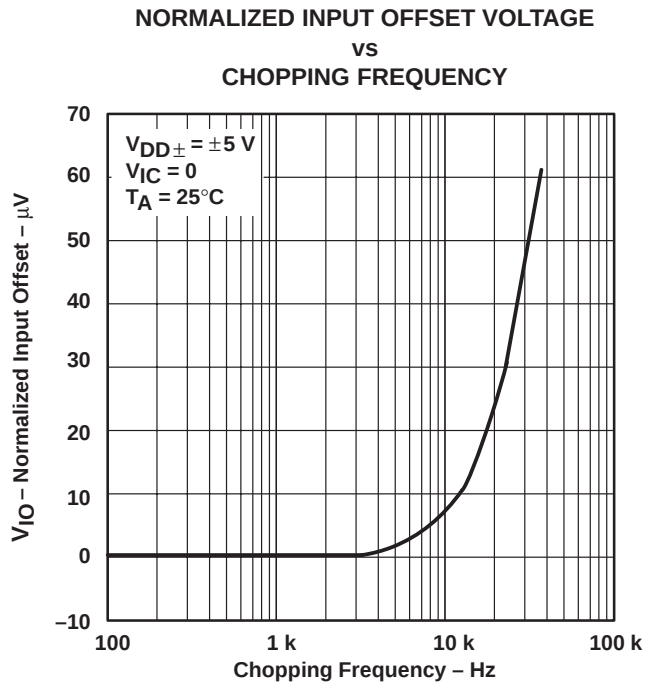


Figure 1

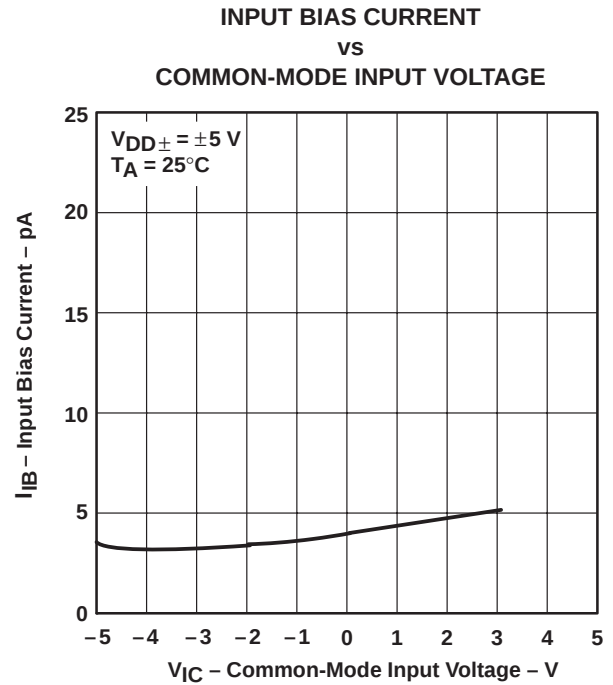


Figure 2

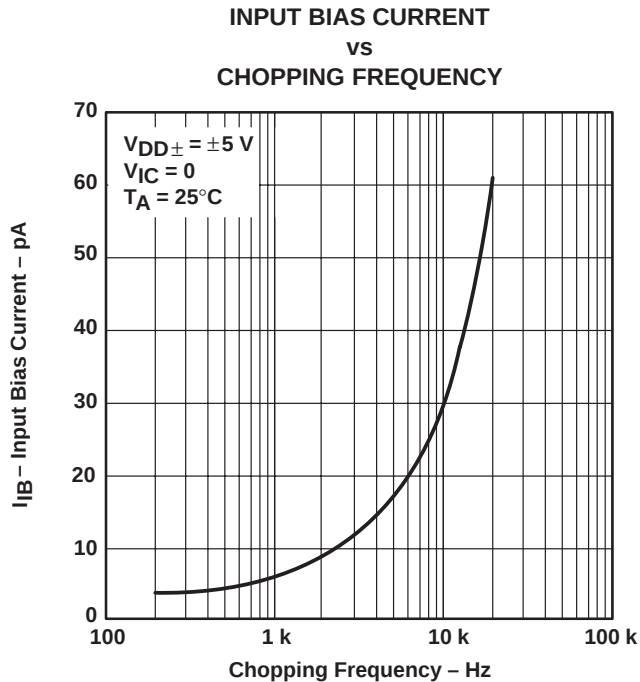


Figure 3

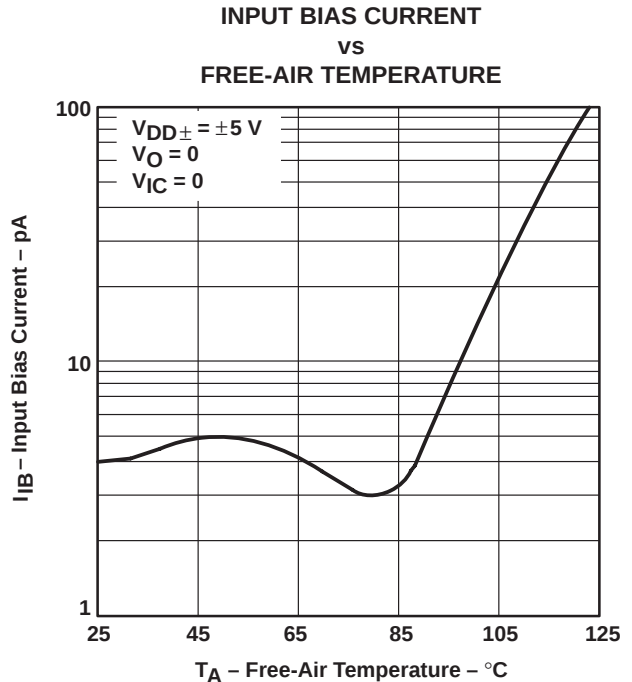


Figure 4

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

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### TYPICAL CHARACTERISTICS†

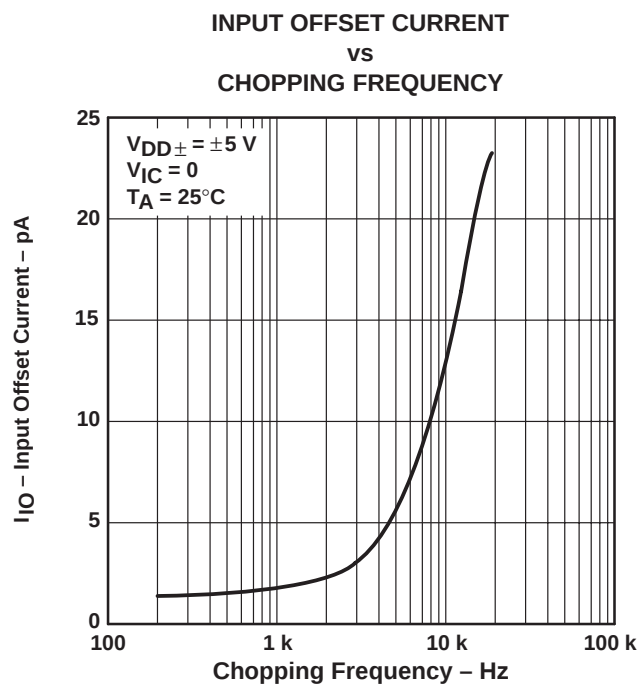


Figure 5

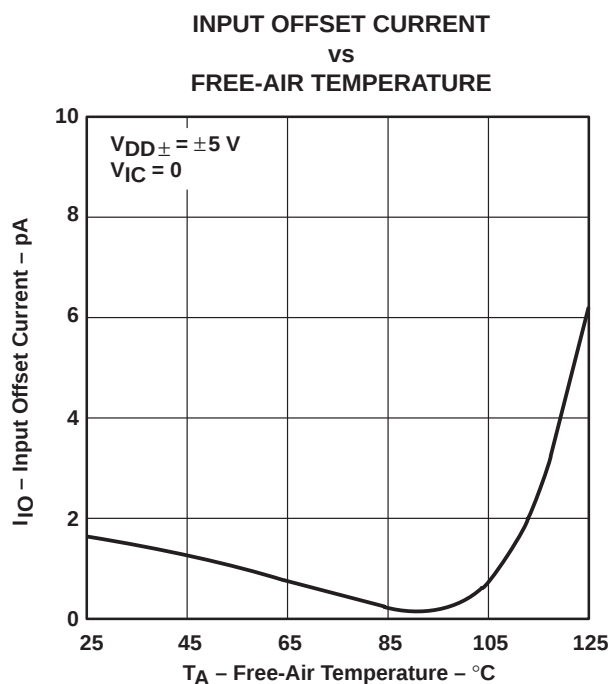


Figure 6

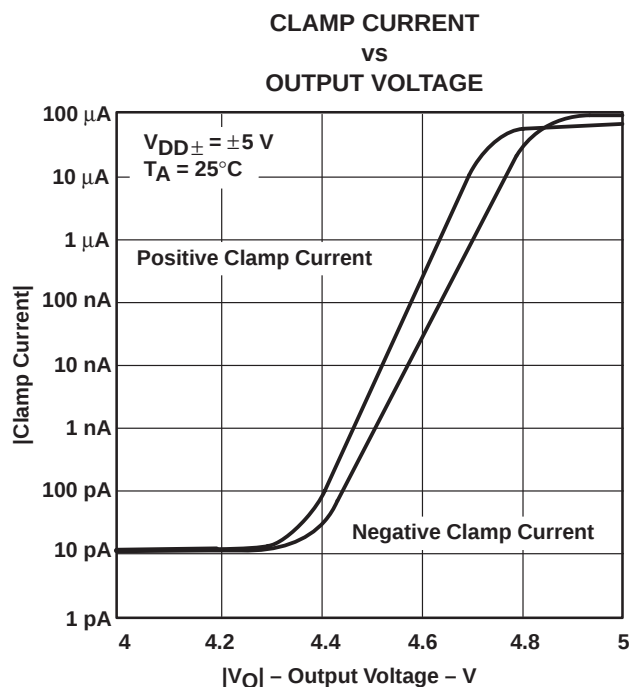


Figure 7

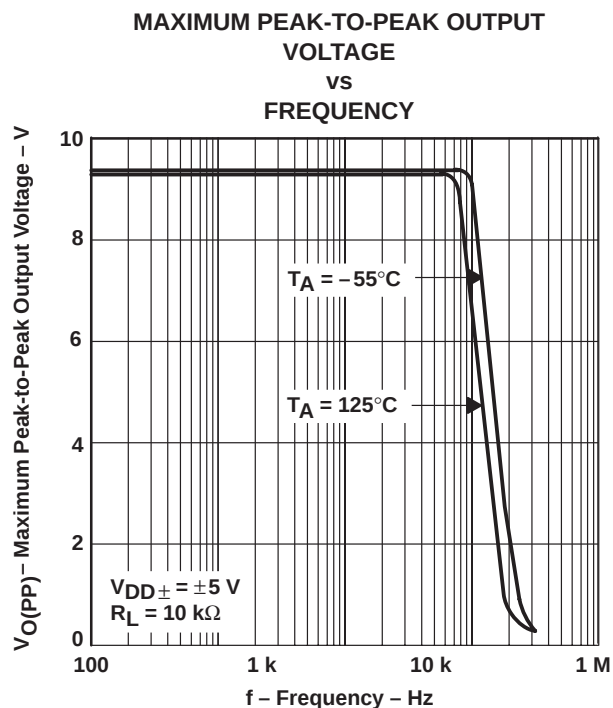


Figure 8

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

## TYPICAL CHARACTERISTICS†

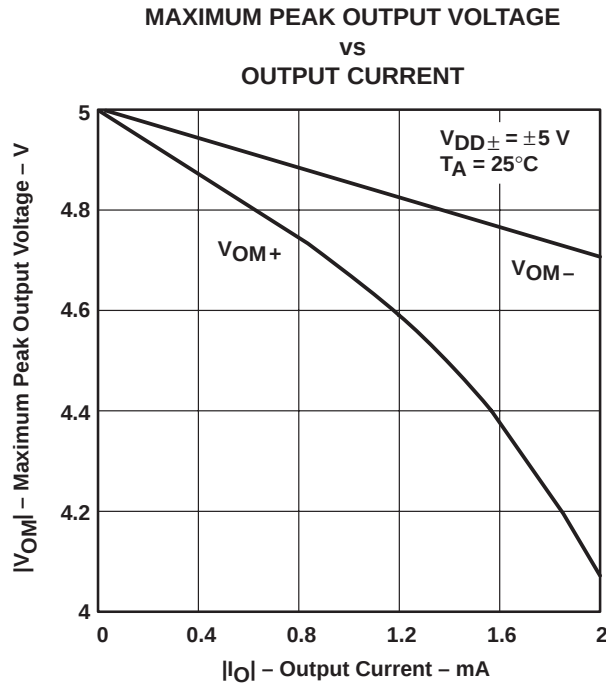


Figure 9

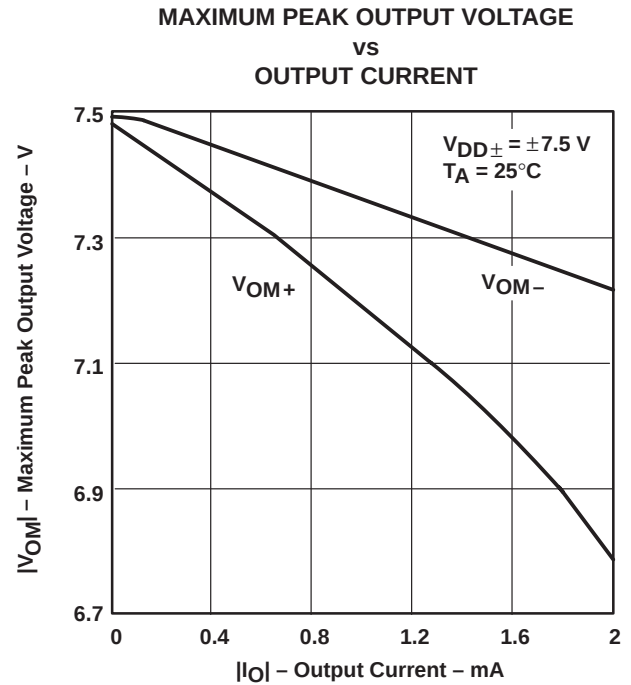


Figure 10

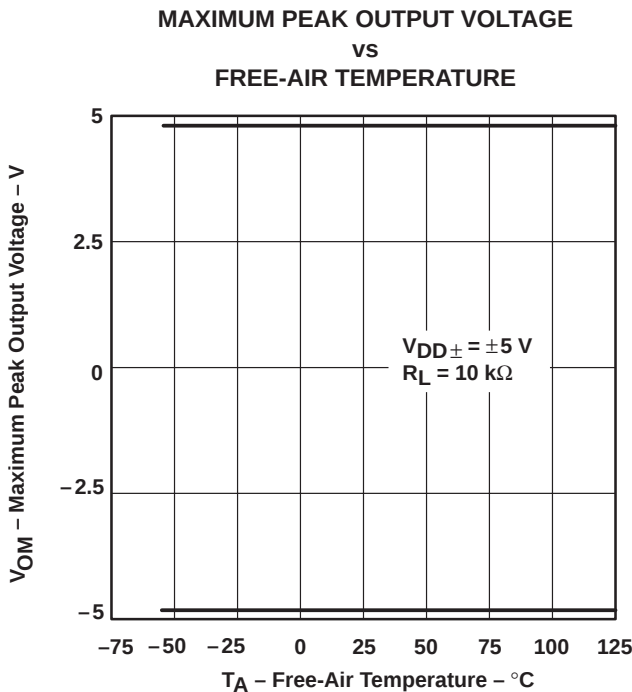


Figure 11

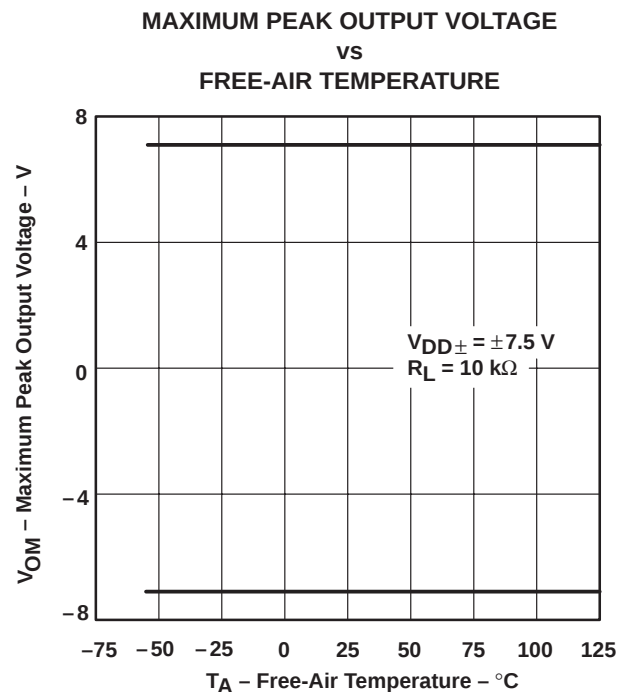


Figure 12

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

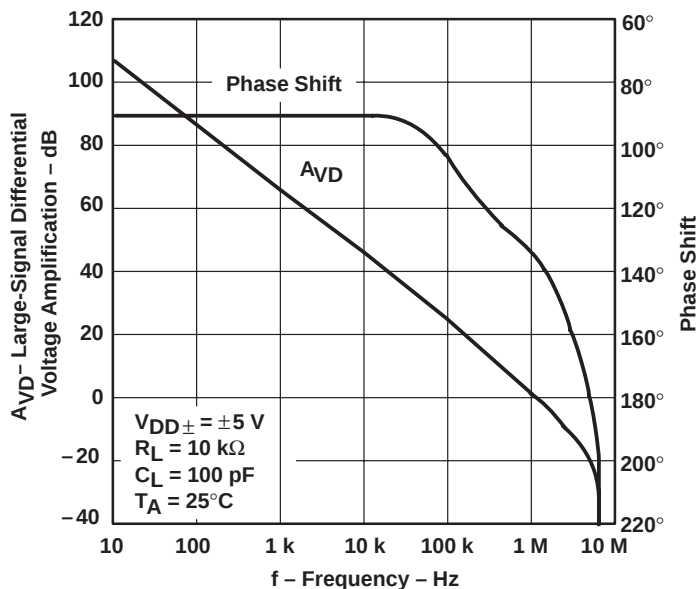
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**TYPICAL CHARACTERISTICS†**

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

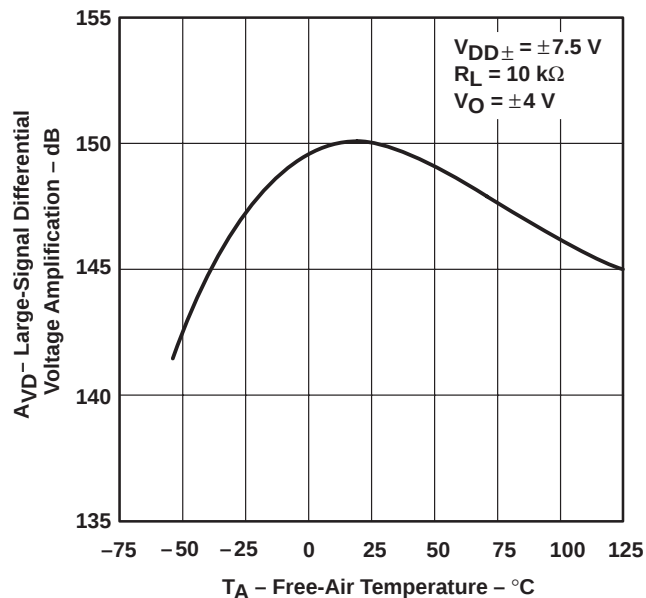
**vs  
FREQUENCY**



**Figure 13**

**LARGE-SIGNAL DIFFERENTIAL VOLTAGE  
AMPLIFICATION**

**vs  
FREE-AIR TEMPERATURE**



**Figure 14**

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

## TYPICAL CHARACTERISTICS†

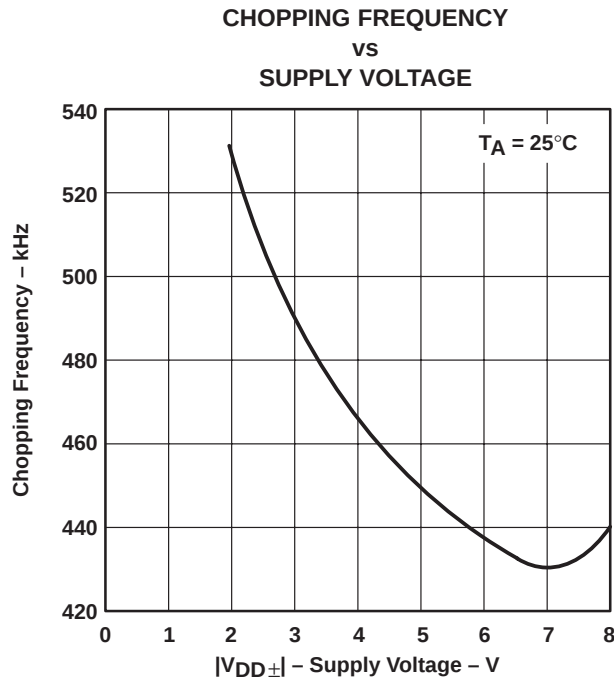


Figure 15

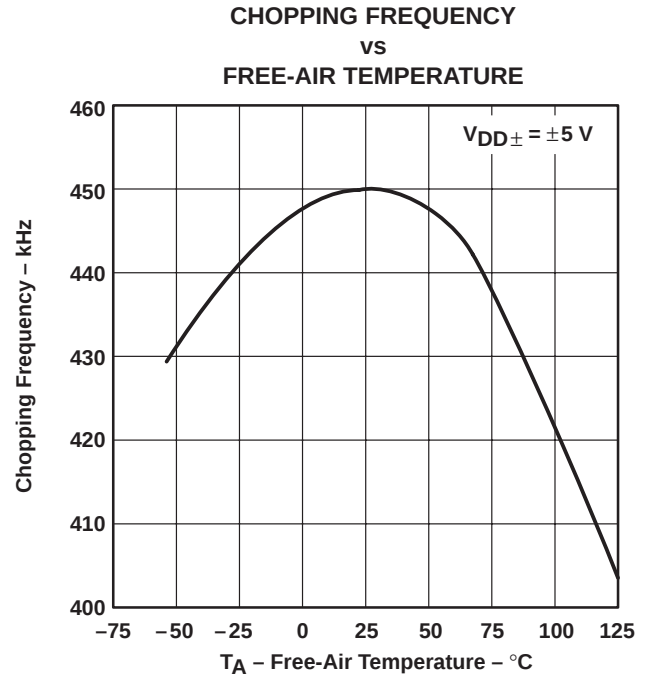


Figure 16

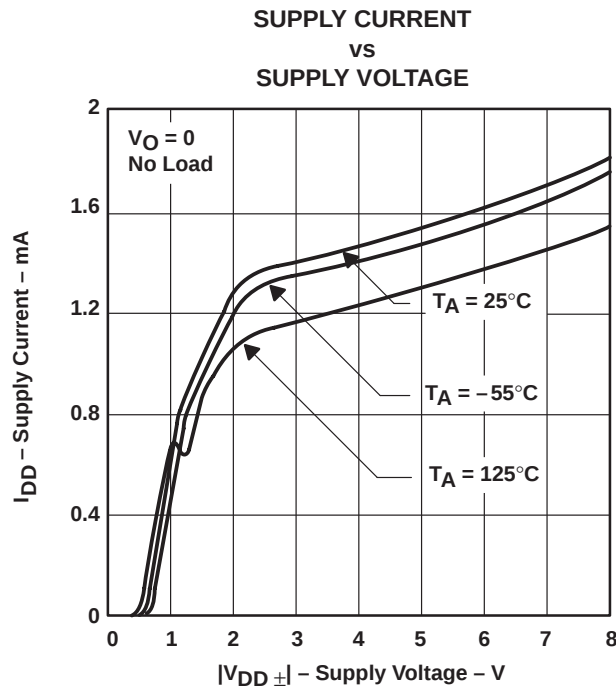


Figure 17

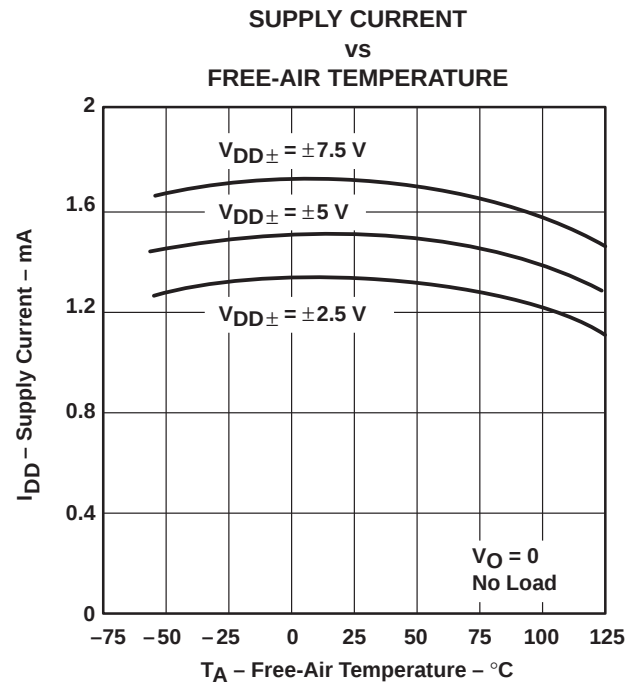


Figure 18

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

# TLC2652, TLC2652A, TLC2652Y

## Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED OPERATIONAL AMPLIFIERS

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### TYPICAL CHARACTERISTICS†

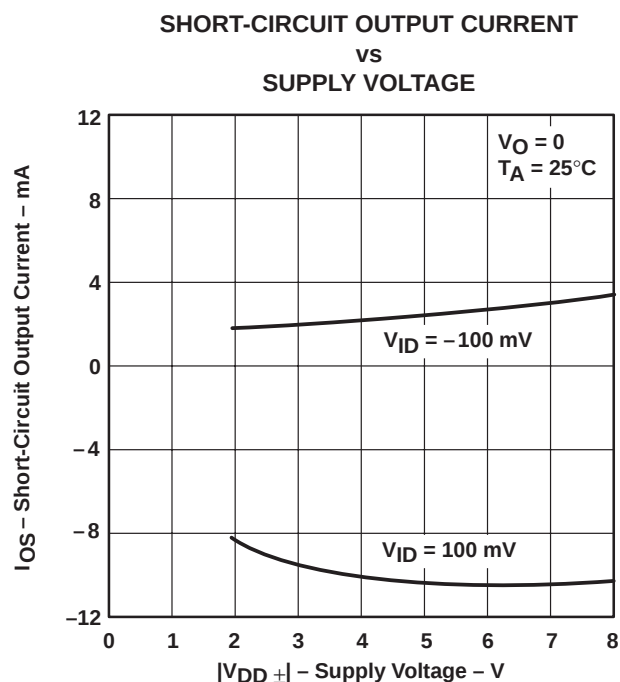


Figure 19

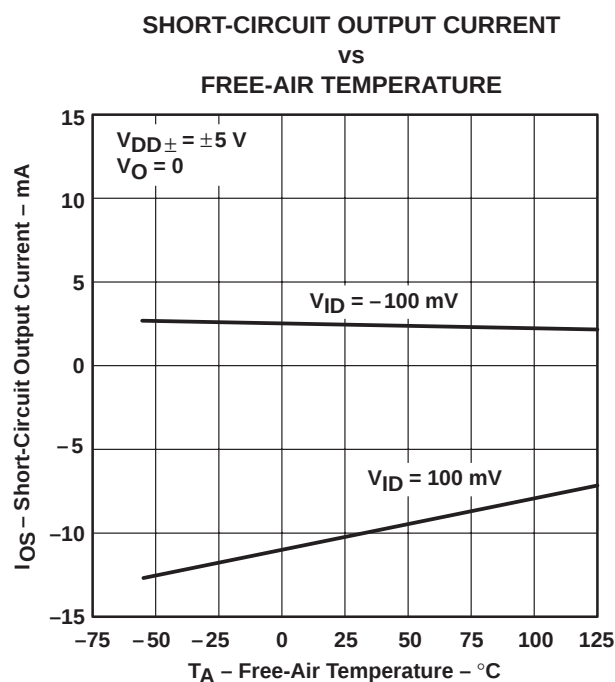


Figure 20

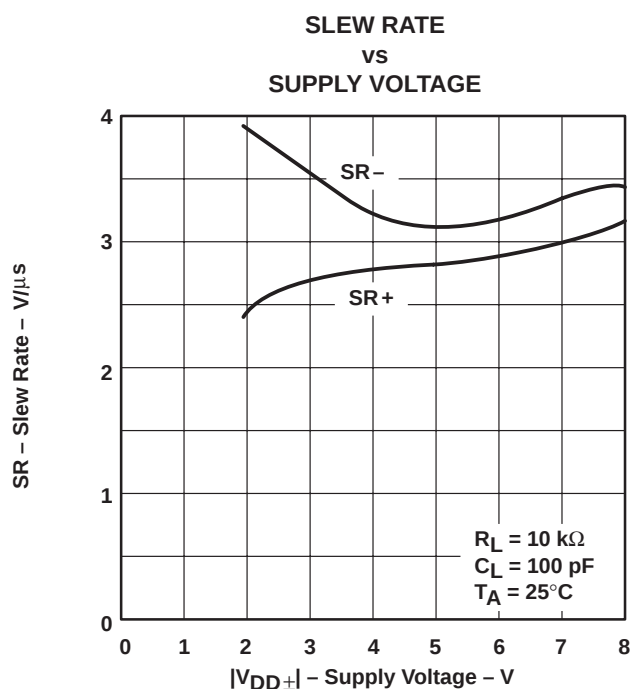


Figure 21

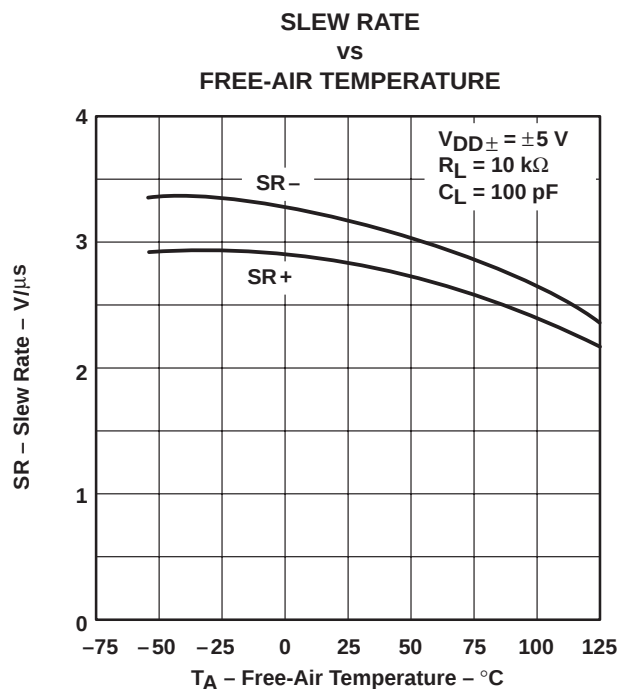


Figure 22

† 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**

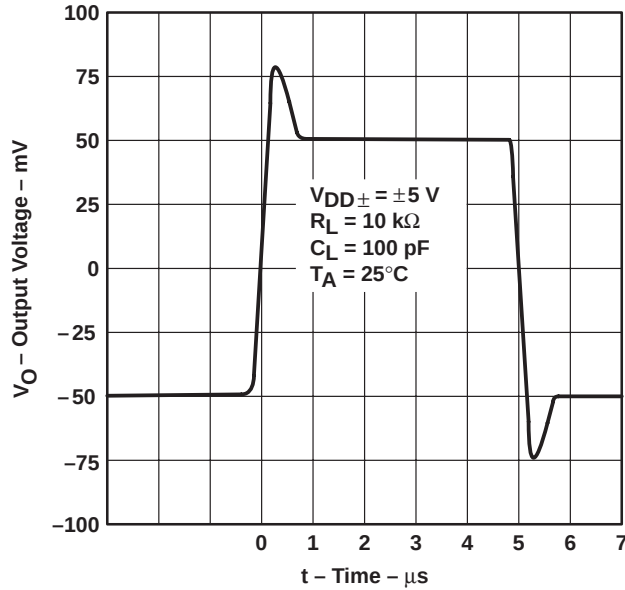


Figure 23

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

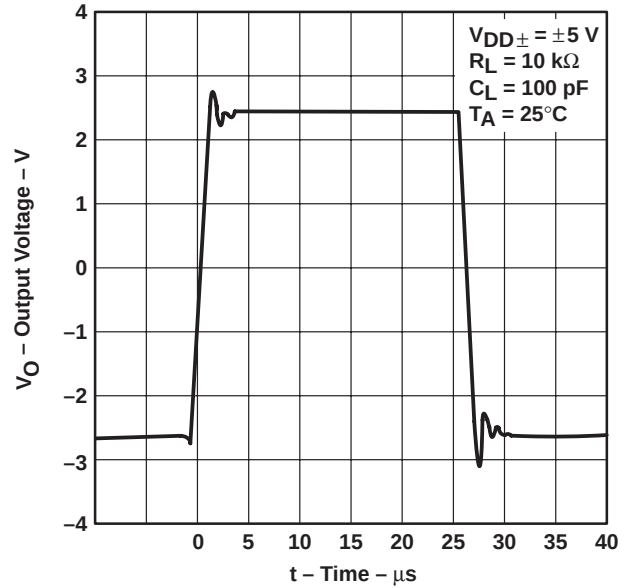


Figure 24

**PEAK-TO-PEAK INPUT NOISE VOLTAGE  
VS  
CHOPPING FREQUENCY**

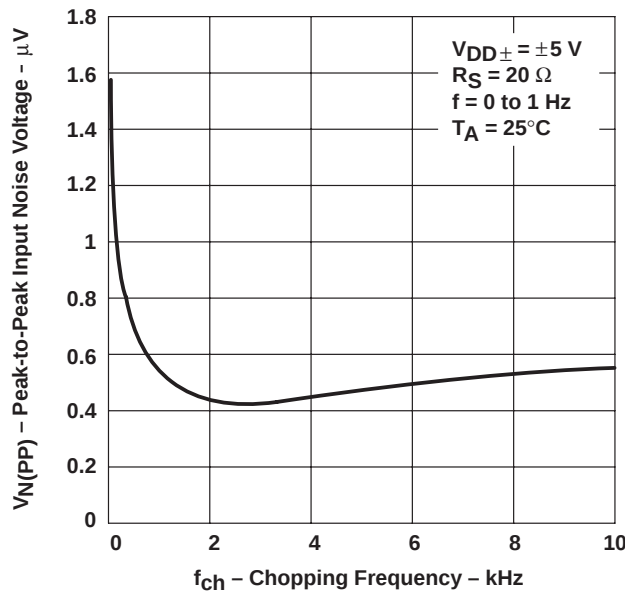


Figure 25

**PEAK-TO-PEAK INPUT NOISE VOLTAGE  
VS  
CHOPPING FREQUENCY**

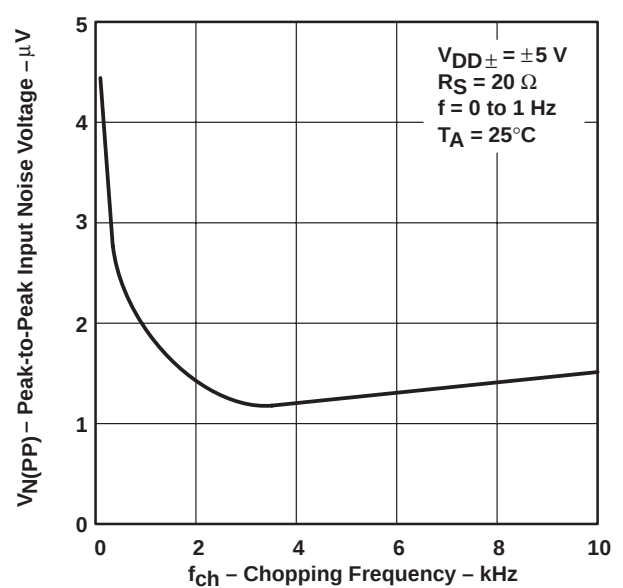


Figure 26

# TLC2652, TLC2652A, TLC2652Y

## Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED OPERATIONAL AMPLIFIERS

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### TYPICAL CHARACTERISTICS†

EQUIVALENT INPUT NOISE VOLTAGE  
VS  
FREQUENCY

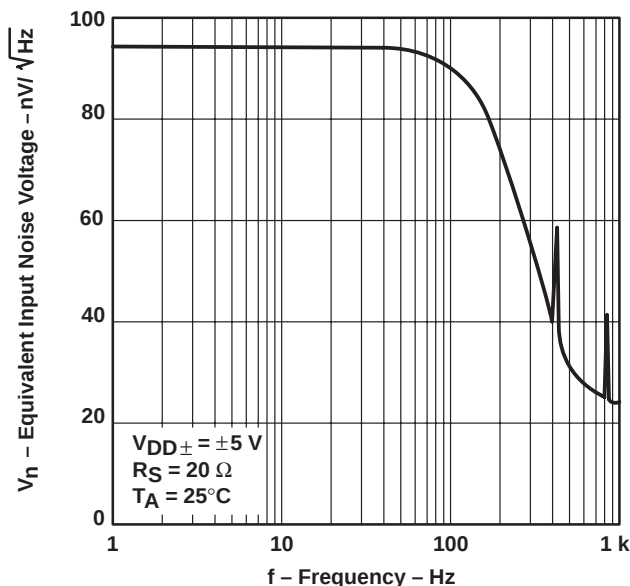


Figure 27

GAIN-BANDWIDTH PRODUCT  
VS  
SUPPLY VOLTAGE

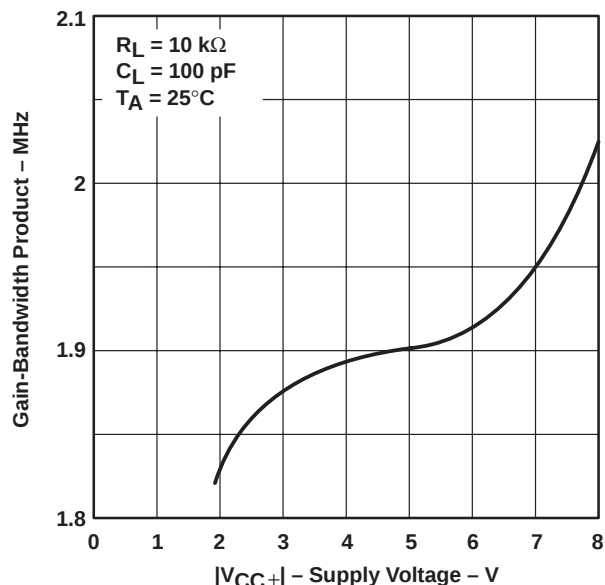


Figure 28

GAIN-BANDWIDTH PRODUCT  
VS  
FREE-AIR TEMPERATURE

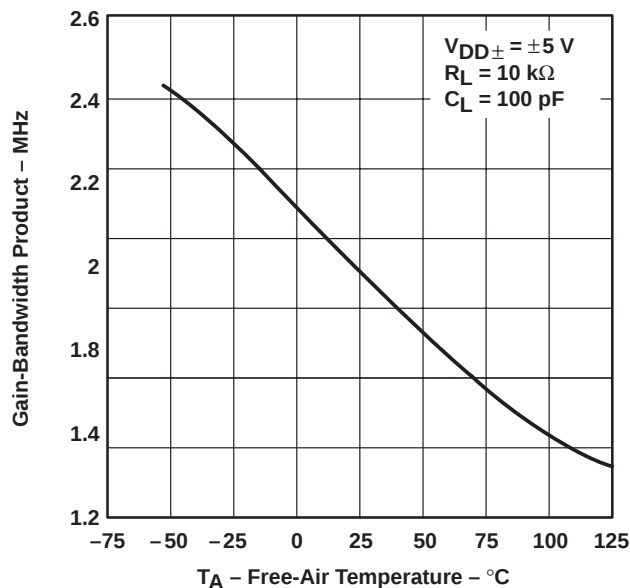


Figure 29

PHASE MARGIN  
VS  
SUPPLY VOLTAGE

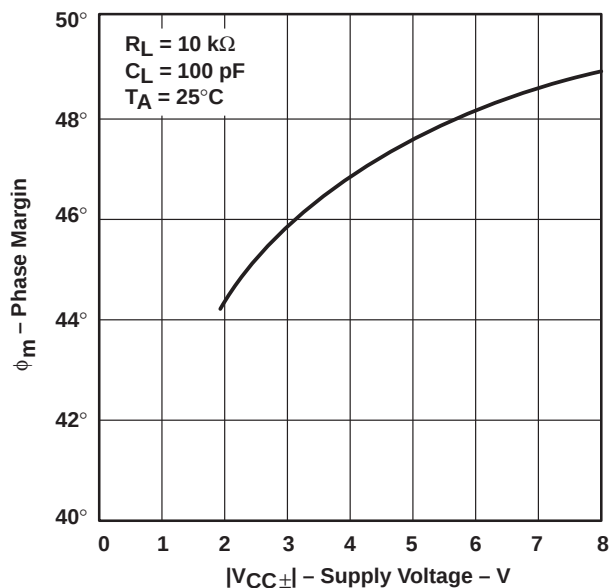
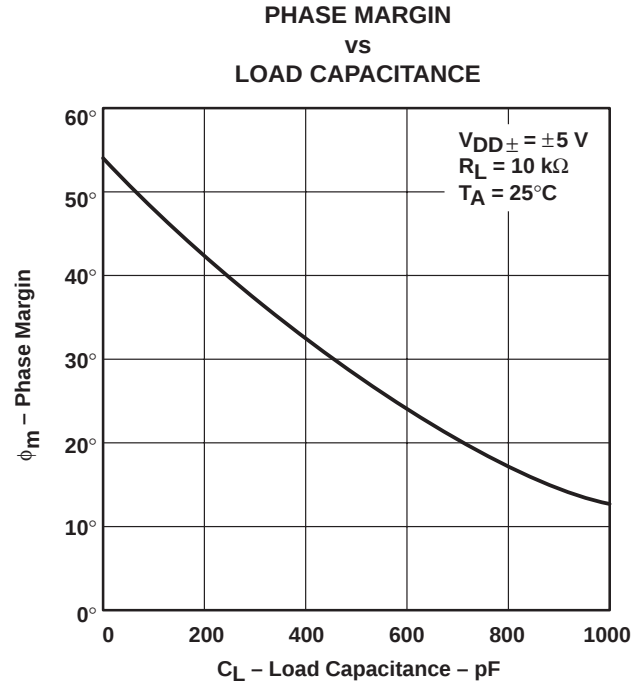
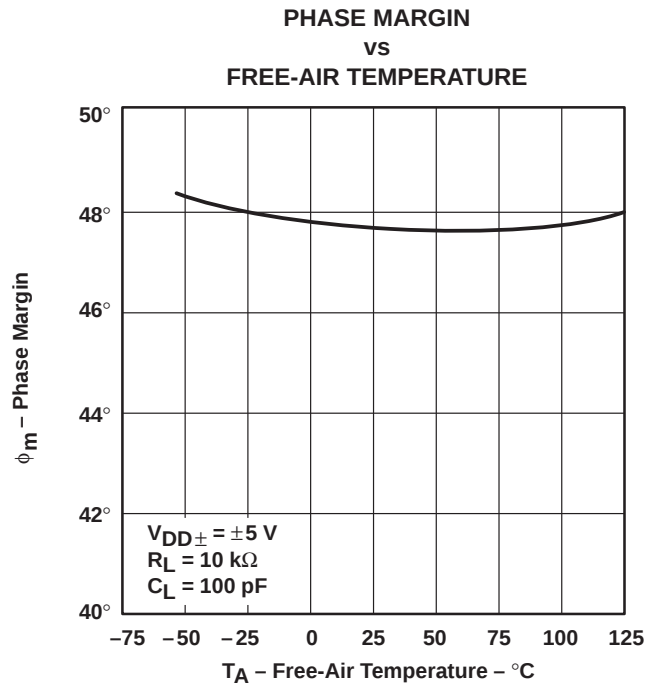


Figure 30

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

## TYPICAL CHARACTERISTICS†



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

## APPLICATION INFORMATION

### capacitor selection and placement

The two important factors to consider when selecting external capacitors  $C_{XA}$  and  $C_{XB}$  are leakage and dielectric absorption. Both factors can cause system degradation, negating the performance advantages realized by using the TLC2652.

Degradation from capacitor leakage becomes more apparent with the increasing temperatures. Low-leakage capacitors and standoffs are recommended for operation at  $T_A = 125^\circ\text{C}$ . In addition, guard bands are recommended around the capacitor connections on both sides of the printed circuit board to alleviate problems caused by surface leakage on circuit boards.

Capacitors with high dielectric absorption tend to take several seconds to settle upon application of power, which directly affects input offset voltage. In applications where fast settling of input offset voltage is needed, it is recommended that high-quality film capacitors, such as mylar, polystyrene, or polypropylene, be used. In other applications, however, a ceramic or other low-grade capacitor can suffice.

Unlike many choppers available today, the TLC2652 is designed to function with values of  $C_{XA}$  and  $C_{XB}$  in the range of  $0.1\ \mu\text{F}$  to  $1\ \mu\text{F}$  without degradation to input offset voltage or input noise voltage. These capacitors should be located as close as possible to the  $C_{XA}$  and  $C_{XB}$  pins and returned to either  $V_{DD-}$  or C RETURN. On many choppers, connecting these capacitors to  $V_{DD-}$  causes degradation in noise performance. This problem is eliminated on the TLC2652.

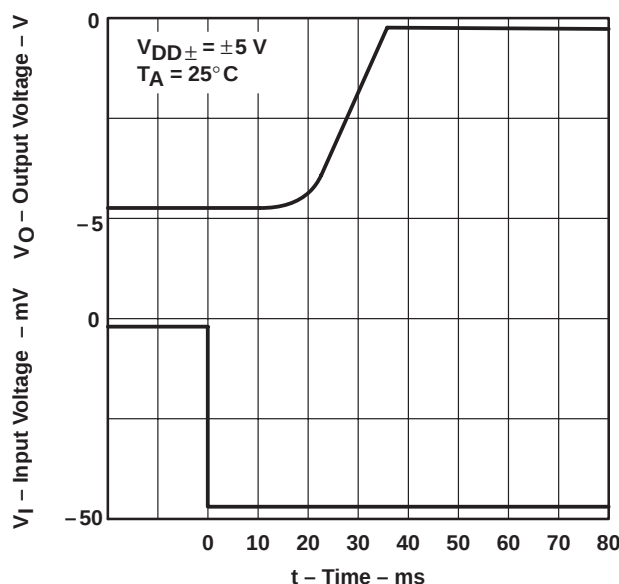
## APPLICATION INFORMATION

### internal/external clock

The TLC2652 has an internal clock that sets the chopping frequency to a nominal value of 450 Hz. On 8-pin packages, the chopping frequency can only be controlled by the internal clock; however, on all 14-pin packages and the 20-pin FK package, the device chopping frequency can be set by the internal clock or controlled externally by use of the INT/EXT and CLK IN pins. To use the internal 450-Hz clock, no connection is necessary. If external clocking is desired, connect INT/EXT to  $V_{DD-}$  and the external clock to CLK IN. The external clock trip point is 2.5 V above the negative rail; however, CLK IN can be driven from the negative rail to 5 V above the negative rail. If this level is exceeded, damage could occur to the device unless the current into CLK IN is limited to  $\pm 5$  mA. When operating in the single-supply configuration, this feature allows the TLC2652 to be driven directly by 5-V TTL and CMOS logic. A divide-by-two frequency divider interfaces with CLK IN and sets the clock chopping frequency. The duty cycle of the external is not critical but should be kept between 30% and 60%.

### overload recovery/output clamp

When large differential input voltage conditions are applied to the TLC2652, the nulling loop attempts to prevent the output from saturating by driving  $C_{XA}$  and  $C_{XB}$  to internally-clamped voltage levels. Once the overdrive condition is removed, a period of time is required to allow the built-up charge to dissipate. This time period is defined as overload recovery time (see Figure 33). Typical overload recovery time for the TLC2652 is significantly faster than competitive products; however, if required, this time can be reduced further by use of internal clamp circuitry accessible through CLAMP if required.



**Figure 33. Overload Recovery**

The clamp is a switch that is automatically activated when the output is approximately 1 V from either supply rail. When connected to the inverting input (in parallel with the closed-loop feedback resistor), the closed-loop gain is reduced, and the TLC2652 output is prevented from going into saturation. Since the output must source sink current through the switch (see Figure 7), the maximum output voltage swing is slightly reduced.

### thermoelectric effects

To take advantage of the extremely low offset voltage drift of the TLC2652, care must be taken to compensate for the thermoelectric effects present when two dissimilar metals are brought into contact with each other (such as device leads being soldered to a printed circuit board). Dissimilar metal junctions can produce thermoelectric voltages in the range of several microvolts per degree Celsius (orders of magnitude greater than the 0.01- $\mu$ V/°C typical of the TLC2652).

To help minimize thermoelectric effects, careful attention should be paid to component selection and circuit-board layout. Avoid the use of nonsoldered connections (such as sockets, relays, switches, etc.) in the input signal path. Cancel thermoelectric effects by duplicating the number of components and junctions in each device input. The use of low-thermoelectric-coefficient components, such as wire-wound resistors, is also beneficial.

## APPLICATION INFORMATION

### latch-up avoidance

Because CMOS devices are susceptible to latch-up due to their inherent parasitic thyristors, the TLC2652 inputs and output are designed to withstand –100-mA surge currents without sustaining latch-up; however, techniques to reduce the chance of latch-up should be used whenever possible. Internal protection diodes should not, by design, be forward biased. Applied input and output voltages should not exceed the supply voltage by more than 300 mV. Care should be exercised when using capacitive coupling on pulse generators. Supply transients should be shunted by the use of decoupling capacitors (0.1  $\mu$ F typical) located across the supply rails as close to the device as possible.

The current path established if latch-up occurs is usually between the supply rails and is limited only by the impedance of the power supply and the forward resistance of the parasitic thyristor. The chance of latch-up occurring increases with increasing temperature and supply voltage.

### electrostatic discharge protection

The TLC2652 incorporates internal ESD-protection circuits that prevent functional failures at voltages at or below 2000 V. Care should be exercised in handling these devices, as exposure to ESD may result in degradation of the device parametric performance.

### theory of operation

Chopper-stabilized operational amplifiers offer the best dc performance of any monolithic operational amplifier. This superior performance is the result of using two operational amplifiers, a main amplifier and a nulling amplifier, plus oscillator-controlled logic and two external capacitors to create a system that behaves as a single amplifier. With this approach, the TLC2652 achieves submicrovolt input offset voltage, submicrovolt noise voltage, and offset voltage variations with temperature in the nV/°C range.

The TLC2652 on-chip control logic produces two dominant clock phases: a nulling phase and an amplifying phase. The term chopper-stabilized derives from the process of switching between these two clock phases. Figure 34 shows a simplified block diagram of the TLC2652. Switches A and B are make-before-break types.

During the nulling phase, switch A is closed shorting the nulling amplifier inputs together and allowing the nulling amplifier to reduce its own input offset voltage by feeding its output signal back to an inverting input node. Simultaneously, external capacitor  $C_{XA}$  stores the nulling potential to allow the offset voltage of the amplifier to remain nulled during the amplifying phase.

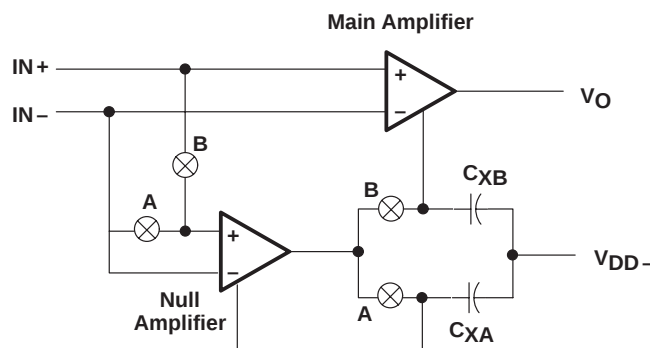


Figure 34. TLC2652 Simplified Block Diagram

## APPLICATION INFORMATION

### theory of operation (continued)

During the amplifying phase, switch B is closed connecting the output of the nulling amplifier to a noninverting input of the main amplifier. In this configuration, the input offset voltage of the main amplifier is nulled. Also, external capacitor  $C_{XB}$  stores the nulling potential to allow the offset voltage of the main amplifier to remain nulled during the next nulling phase.

This continuous chopping process allows offset voltage nulling during variations in time and temperature over the common-mode input voltage range and power supply range. In addition, because the low-frequency signal path is through both the null and main amplifiers, extremely high gain is achieved.

The low-frequency noise of a chopper amplifier depends on the magnitude of the component noise prior to chopping and the capability of the circuit to reduce this noise while chopping. The use of the Advanced LinCMOS process, with its low-noise analog MOS transistors and patent-pending input stage design, significantly reduces the input noise voltage.

The primary source of nonideal operation in chopper-stabilized amplifiers is error charge from the switches. As charge imbalance accumulates on critical nodes, input offset voltage can increase, especially with increasing chopping frequency. This problem has been significantly reduced in the TLC2652 by use of a patent-pending compensation circuit and the Advanced LinCMOS process.

The TLC2652 incorporates a feed-forward design that ensures continuous frequency response. Essentially, the gain magnitude of the nulling amplifier and compensation network crosses unity at the break frequency of the main amplifier. As a result, the high-frequency response of the system is the same as the frequency response of the main amplifier. This approach also ensures that the slewing characteristics remain the same during both the nulling and amplifying phases.

TLC2652, TLC2652A, TLC2652Y  
Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED  
OPERATIONAL AMPLIFIERS

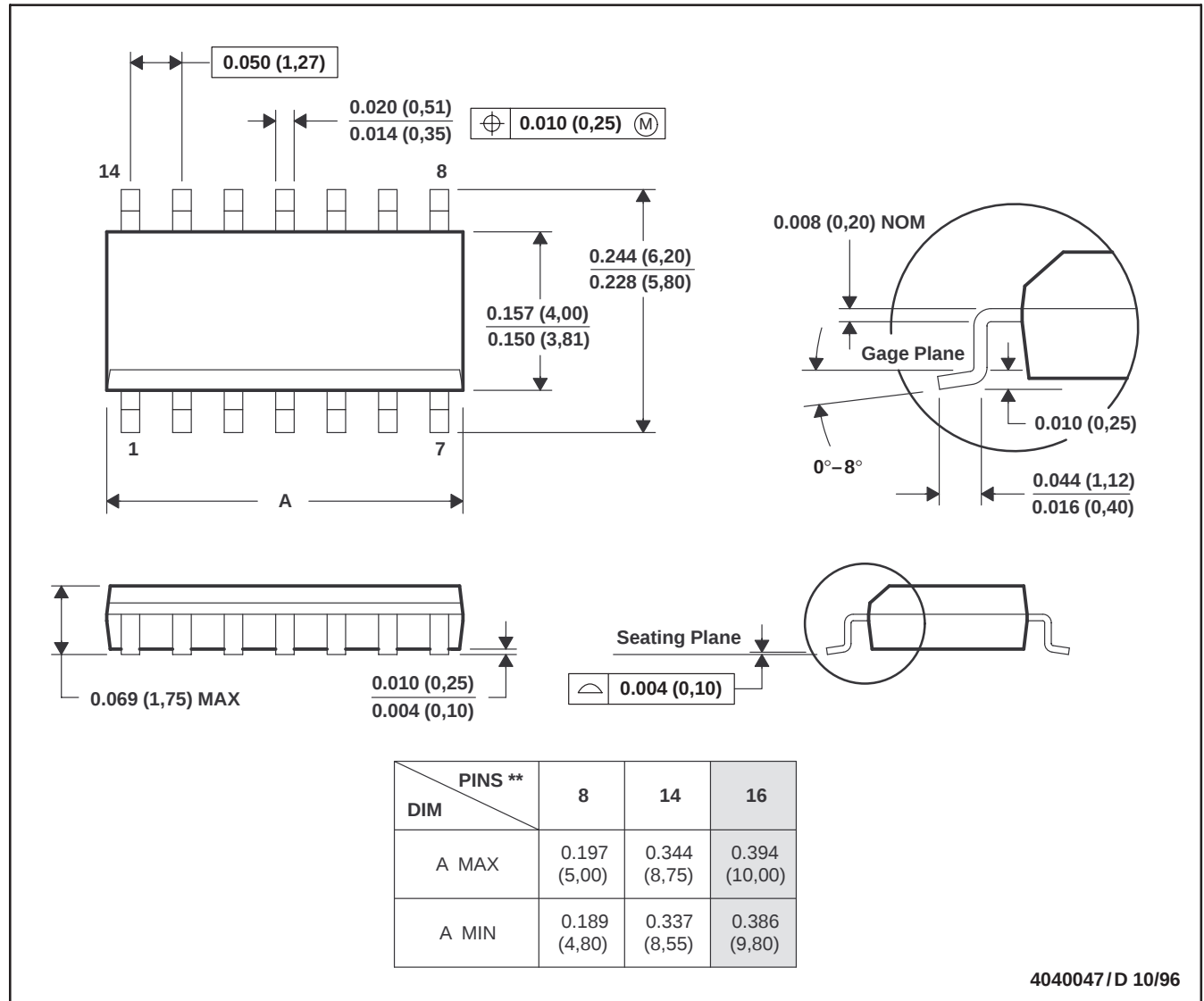
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## MECHANICAL DATA

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

**PLASTIC SMALL-OUTLINE PACKAGE**

14 PIN SHOWN



- NOTES: A. All linear dimensions are in inches (millimeters).  
 B. This drawing is subject to change without notice.  
 C. Body dimensions do not include mold flash or protrusion, not to exceed 0.006 (0,15).  
 D. Falls within JEDEC MS-012

# TLC2652, TLC2652A, TLC2652Y

## Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED OPERATIONAL AMPLIFIERS

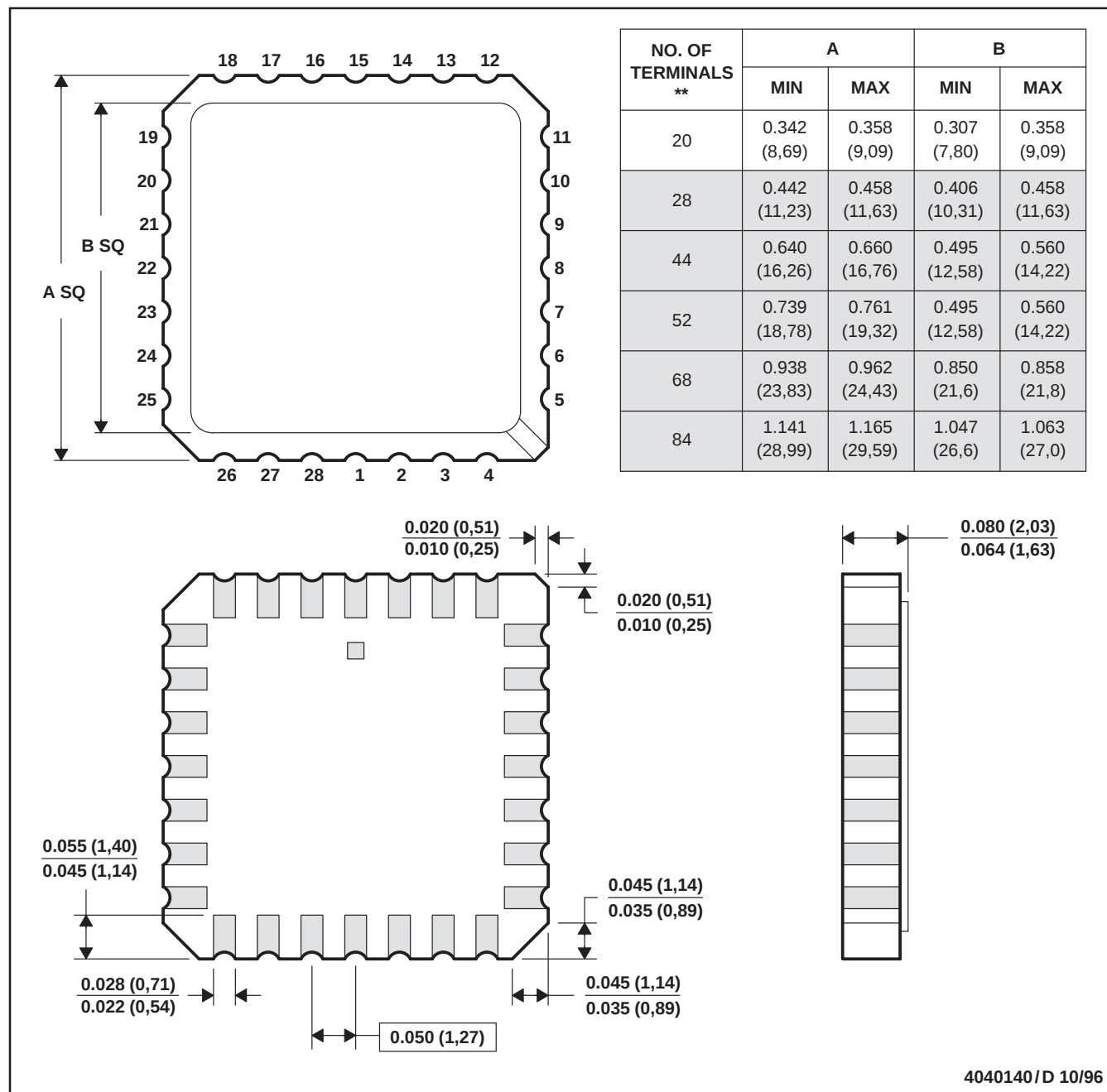
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### MECHANICAL DATA

FK (S-CQCC-N\*\*)

LEADLESS CERAMIC CHIP CARRIER

28 TERMINAL SHOWN



4040140/D 10/96

- NOTES:
- A. All linear dimensions are in inches (millimeters).
  - B. This drawing is subject to change without notice.
  - C. This package can be hermetically sealed with a metal lid.
  - D. The terminals are gold plated.
  - E. Falls within JEDEC MS-004

**TLC2652, TLC2652A, TLC2652Y**  
**Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED**  
**OPERATIONAL AMPLIFIERS**

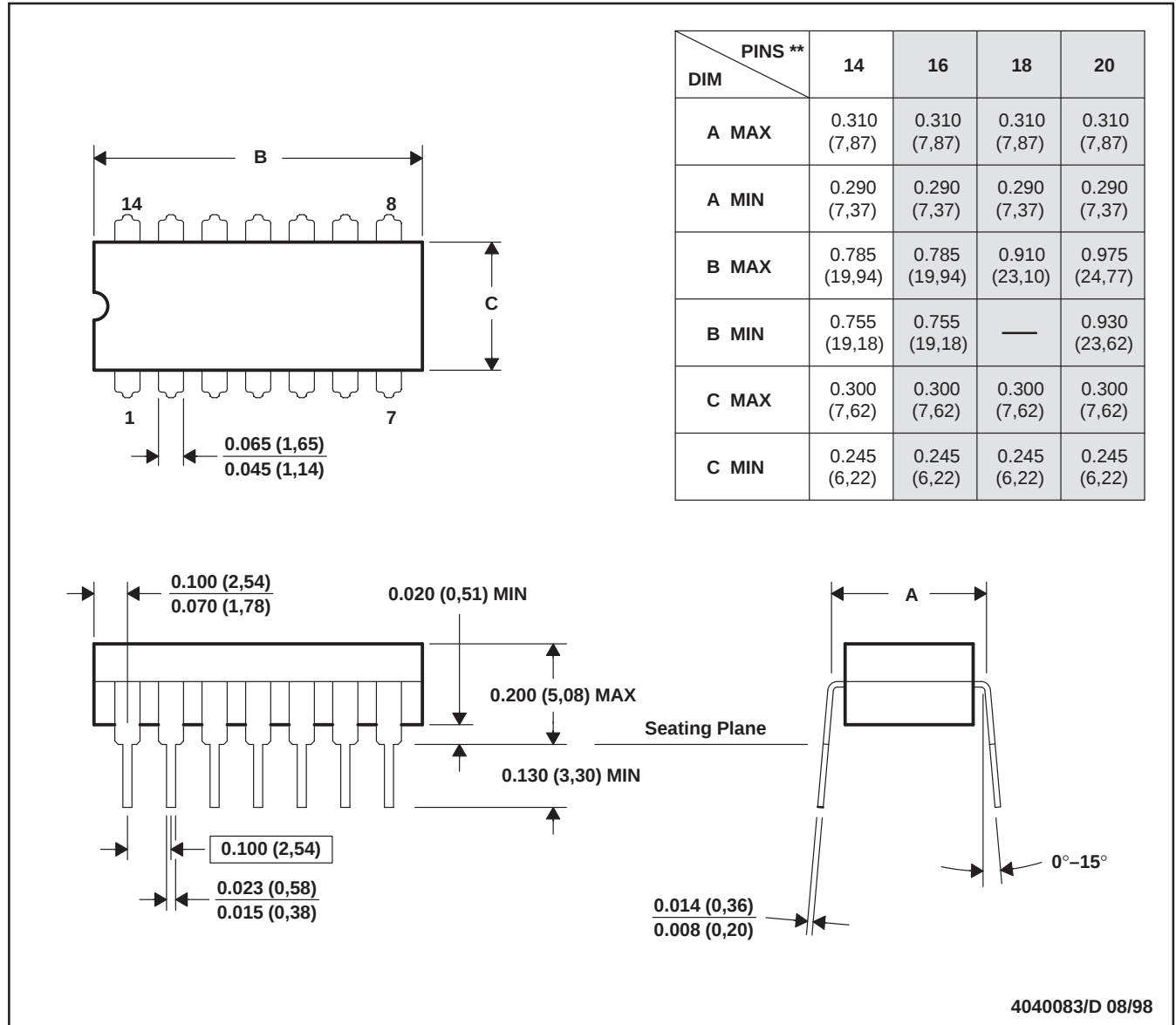
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**MECHANICAL DATA**

**J (R-GDIP-T\*\*)**

**CERAMIC DUAL-IN-LINE PACKAGE**

14 PIN SHOWN



- NOTES: A. All linear dimensions are in inches (millimeters).  
 B. This drawing is subject to change without notice.  
 C. This package can be hermetically sealed with a ceramic lid using glass frit.  
 D. Index point is provided on cap for terminal identification only on press ceramic glass frit seal only.  
 E. Falls within MIL STD 1835 GDIP1-T14, GDIP1-T16, GDIP1-T18, GDIP1-T20, and GDIP1-T22.

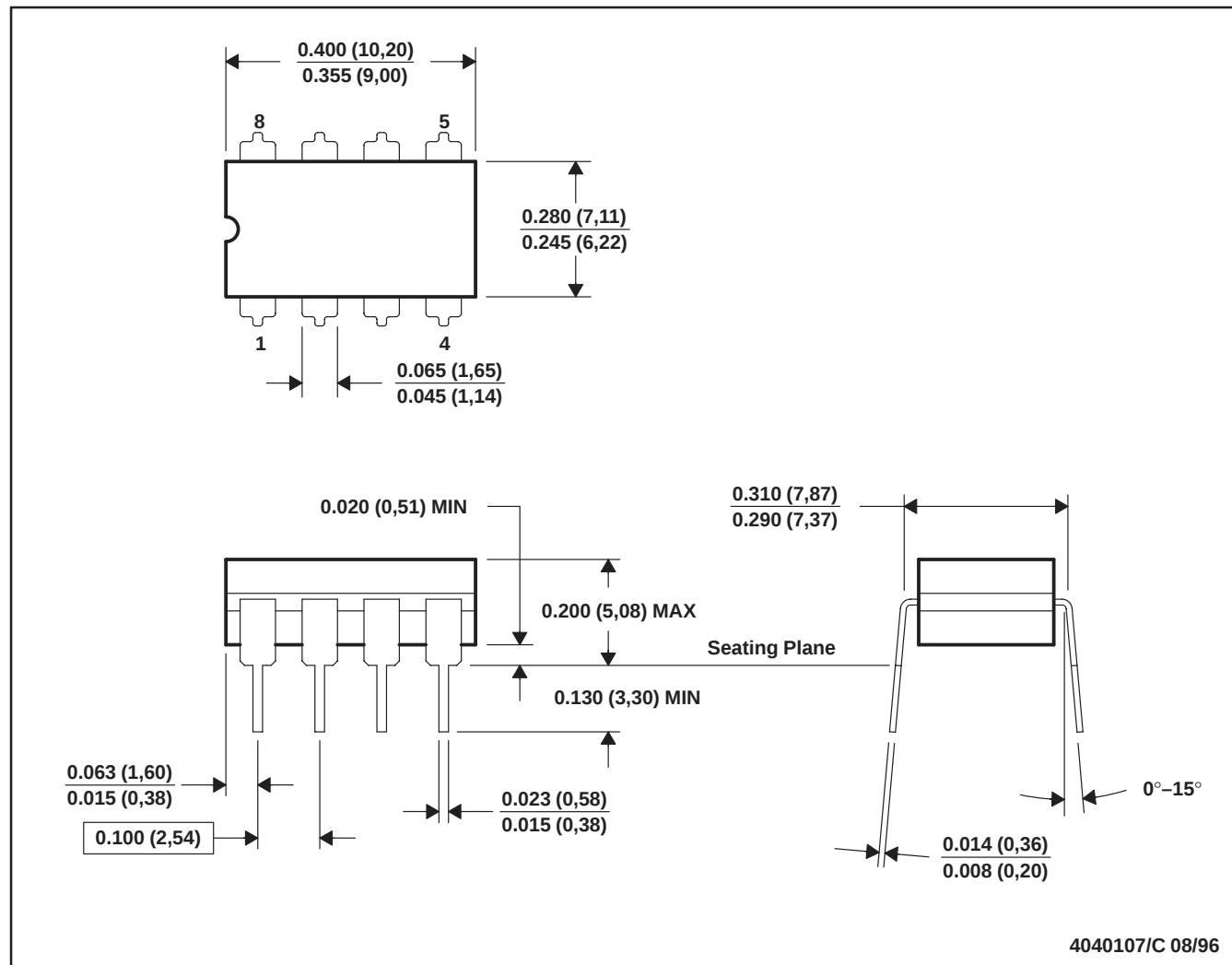
**TLC2652, TLC2652A, TLC2652Y**  
**Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED**  
**OPERATIONAL AMPLIFIERS**

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**MECHANICAL DATA**

**JG (R-GDIP-T8)**

**CERAMIC DUAL-IN-LINE PACKAGE**



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

**TLC2652, TLC2652A, TLC2652Y**  
**Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED**  
**OPERATIONAL AMPLIFIERS**

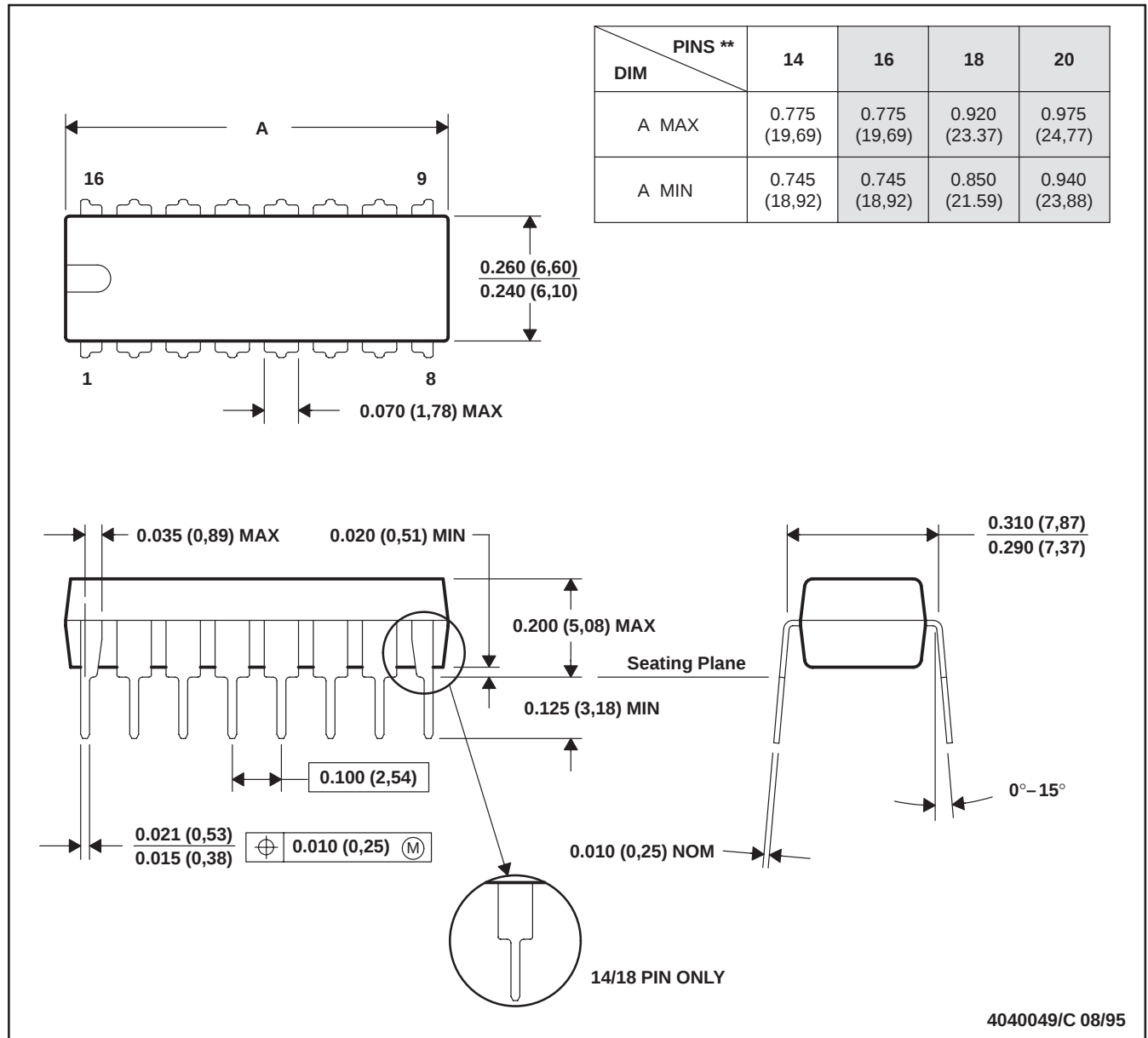
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**MECHANICAL DATA**

**N (R-PDIP-T\*\*)**

**PLASTIC DUAL-IN-LINE PACKAGE**

**16 PIN SHOWN**



- NOTES: A. All linear dimensions are in inches (millimeters).  
 B. This drawing is subject to change without notice.  
 C. Falls within JEDEC MS-001 (20 pin package is shorter than MS-001.)

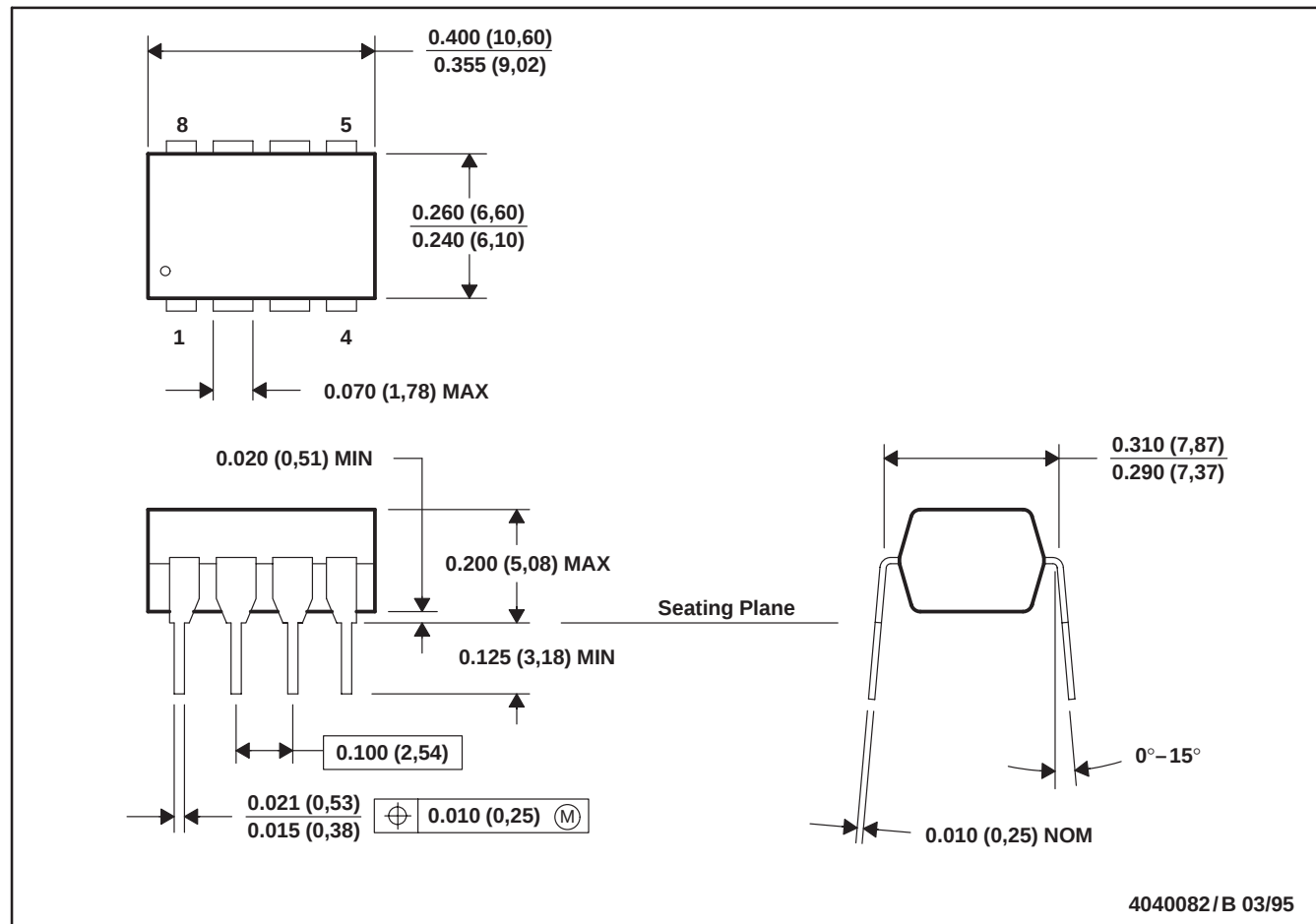
**TLC2652, TLC2652A, TLC2652Y**  
**Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED**  
**OPERATIONAL AMPLIFIERS**

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**MECHANICAL DATA**

**P (R-PDIP-T8)**

**PLASTIC DUAL-IN-LINE PACKAGE**



- NOTES: A. All linear dimensions are in inches (millimeters).  
 B. This drawing is subject to change without notice.  
 C. Falls within JEDEC MS-001

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