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MOTOROLA

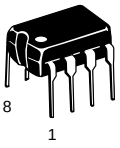
# MC33201
# MC33202
# MC33204

# Rail-to-Rail Operational Amplifiers

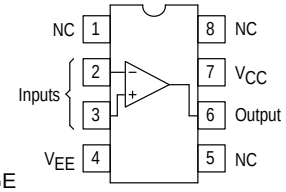
**LOW VOLTAGE**
**RAIL–TO–RAIL**
**OPERATIONAL AMPLIFIERS**

The MC33201/2/4 family of operational amplifiers provide rail–to–rail operation on both the input and output. The inputs can be driven as high as 200 mV beyond the supply rails without phase reversal on the outputs, and the output can swing within 50 mV of each rail. This rail–to–rail operation enables the user to make full use of the supply voltage range available. It is designed to work at very low supply voltages (± 0.9 V) yet can operate with a supply of up to +12 V and ground. Output current boosting techniques provide a high output current capability while keeping the drain current of the amplifier to a minimum. Also, the combination of low noise and distortion with a high slew rate and drive capability make this an ideal amplifier for audio applications.

- Low Voltage, Single Supply Operation (+1.8 V and Ground to +12 V and Ground)
- Input Voltage Range Includes both Supply Rails
- Output Voltage Swings within 50 mV of both Rails
- No Phase Reversal on the Output for Over–driven Input Signals
- High Output Current ($I_{SC}$ = 80 mA, Typ)
- Low Supply Current ($I_D$ = 0.9 mA, Typ)
- 600 Ω Output Drive Capability
- Extended Operating Temperature Ranges (–40° to +105°C and –55° to +125°C)
- Typical Gain Bandwidth Product = 2.2 MHz
- Offered in New TSSOP Package Including Standard SOIC and DIP Packages

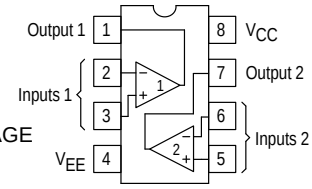



**P SUFFIX**
PLASTIC PACKAGE
CASE 626

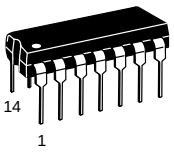



(Single, Top View)

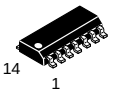
**D SUFFIX**
PLASTIC PACKAGE
CASE 751
(SO–8)




(Dual, Top View)

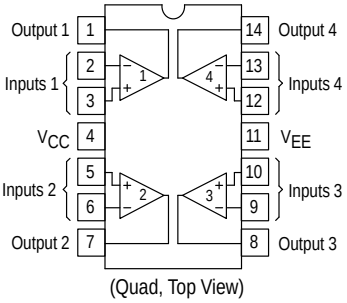



**P SUFFIX**
PLASTIC PACKAGE
CASE 646




**D SUFFIX**
PLASTIC PACKAGE
CASE 751A
(SO–14)

**DTB SUFFIX**
PLASTIC PACKAGE
CASE 948G
(TSSOP–14)




(Quad, Top View)

**ORDERING INFORMATION**

| Operational Amplifier Function | Device | Operating Temperature Range | Package |
|---|---|---|---|
| Single | MC33201D | $T_A$= –40 ° to +105°C | SO–8 |
| | MC33201P | | Plastic DIP |
| | MC33201VD | $T_A$ = –55 ° to +125°C | SO–8 |
| | MC33201VP | | Plastic DIP |
| Dual | MC33202D | $T_A$= –40 ° to +105°C | SO–8 |
| | MC33202P | | Plastic DIP |
| | MC33202VD | $T_A$ = –55 ° to +125°C | SO–8 |
| | MC33202VP | | Plastic DIP |
| Quad | MC33204D | $T_A$= –40 ° to +105°C | SO–14 |
| | MC33204DTB | | TSSOP–14 |
| | MC33204P | | Plastic DIP |
| | MC33204VD | $T_A$ = –55 ° to +125°C | SO–14 |
| | MC33204VDTB | | TSSOP–14 |
| | MC33204VP | | Plastic DIP |

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**DC ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C)

| Characteristic | $V_{CC}$ = 2.0 V | $V_{CC}$ = 3.3 V | $V_{CC}$ = 5.0 V | Unit |
|---|---|---|---|---|
| Input Offset Voltage<br>$V_{IO}$ (max)<br>MC33201<br>MC33202<br>MC33204 | <br><br>± 8.0<br>±10<br>±12 | <br><br>± 8.0<br>±10<br>±12 | <br><br>± 6.0<br>± 8.0<br>±10 | mV |
| Output Voltage Swing<br>$V_{OH}$ ($R_L$ = 10 kΩ)<br>$V_{OL}$ ($R_L$ = 10 kΩ) | <br>1.9<br>0.10 | <br>3.15<br>0.15 | <br>4.85<br>0.15 | <br>$V_{min}$<br>$V_{max}$ |
| Power Supply Current per Amplifier ($I_D$) | 1.125 | 1.125 | 1.125 | mA |

Specifications at $V_{CC}$ = 3.3 V are guaranteed by the 2.0 V and 5.0 V tests. $V_{EE}$ = Gnd.

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage ($V_{CC}$ to $V_{EE}$) | $V_S$ | +13 | V |
| Input Differential Voltage Range | $V_{IDR}$ | (Note 1) | V |
| Common Mode Input Voltage Range (Note 2) | $V_{CM}$ | $V_{CC}$ + 0.5 V to $V_{EE}$ – 0.5 V | V |
| Output Short Circuit Duration | $t_S$ | (Note 3) | sec |
| Maximum Junction Temperature | $T_J$ | +150 | °C |
| Storage Temperature | $T_{stg}$ | – 65 to +150 | °C |
| Maximum Power Dissipation | $P_D$ | (Note 3) | mW |

**NOTES:** 1. The differential input voltage of each amplifier is limited by two internal parallel back–to–back diodes. For additional differential input voltage range, use current limiting resistors in series with the input pins.
2. The input common mode voltage range is limited by internal diodes connected from the inputs to both supply rails. Therefore, the voltage on either input must not exceed either supply rail by more than 500 mV.
3. Power dissipation must be considered to ensure maximum junction temperature ($T_J$) is not exceeded. (See Figure 2)

**DC ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = + 5.0 V, $V_{EE}$ = Ground, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Figure | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Input Offset Voltage ($V_{CM}$ 0 V to 0.5 V, $V_{CM}$ 1.0 V to 5.0 V) | 3 | $\lvert V_{IO} \rvert$ | | | | mV |
| MC33201: $T_A$ = + 25°C | | | – | – | 6.0 | |
| $T_A$ = – 40° to +105°C | | | – | – | 9.0 | |
| $T_A$ = – 55° to +125°C | | | – | – | 13 | |
| MC33202: $T_A$ = + 25°C | | | – | – | 8.0 | |
| $T_A$ = – 40° to +105°C | | | – | – | 11 | |
| $T_A$ = – 55° to +125°C | | | – | – | 14 | |
| MC33204: $T_A$ = + 25°C | | | – | – | 10 | |
| $T_A$ = – 40° to +105°C | | | – | – | 13 | |
| $T_A$ = – 55° to +125°C | | | – | – | 17 | |
| Input Offset Voltage Temperature Coefficient ($R_S$ = 50 Ω) | 4 | $\Delta V_{IO}/\Delta T$ | | | | µV/°C |
| $T_A$ = – 40° to +105°C | | | – | 2.0 | – | |
| $T_A$ = – 55° to +125°C | | | – | 2.0 | – | |
| Input Bias Current ($V_{CM}$ = 0 V to 0.5 V, $V_{CM}$ = 1.0 V to 5.0 V) | 5, 6 | $\lvert I_{IB} \rvert$ | | | | nA |
| $T_A$ = + 25°C | | | – | 80 | 200 | |
| $T_A$ = – 40° to +105°C | | | – | 100 | 250 | |
| $T_A$ = – 55° to +125°C | | | – | – | 500 | |
| Input Offset Current ($V_{CM}$ = 0 V to 0.5 V, $V_{CM}$ = 1.0 V to 5.0 V) | – | $\lvert I_{IO} \rvert$ | | | | nA |
| $T_A$ = + 25°C | | | – | 5.0 | 50 | |
| $T_A$ = – 40° to +105°C | | | – | 10 | 100 | |
| $T_A$ = – 55° to +125°C | | | – | – | 200 | |
| Common Mode Input Voltage Range | – | $V_{ICR}$ | $V_{EE}$ | – | $V_{CC}$ | V |

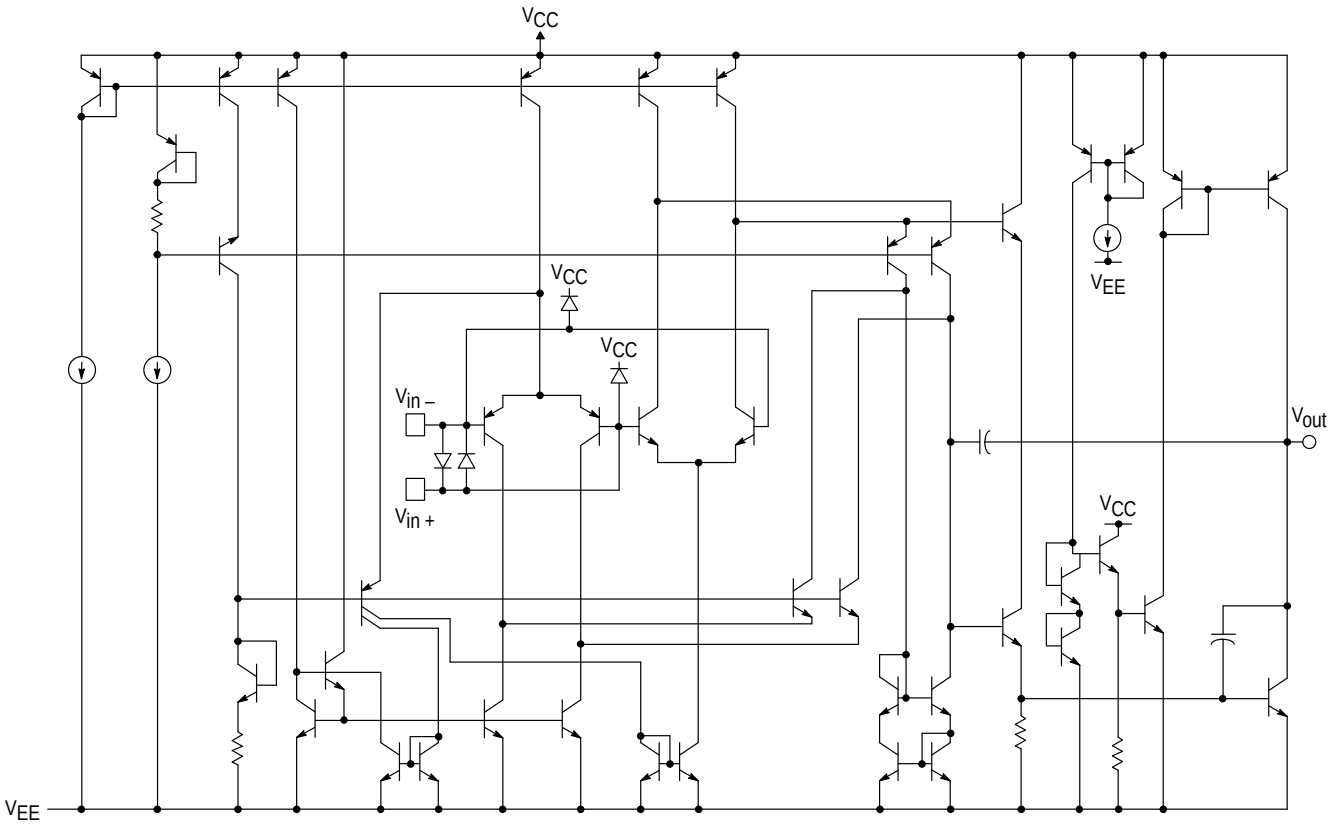
**DC ELECTRICAL CHARACTERISTICS (continued)** ($V_{CC}$ = + 5.0 V, $V_{EE}$ = Ground, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Figure | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Large Signal Voltage Gain ($V_{CC}$ = + 5.0 V, $V_{EE}$ = – 5.0 V)<br>$R_L$ = 10 kΩ<br>$R_L$ = 600 Ω | 7 | $A_{VOL}$ | <br>50<br>25 | <br>300<br>250 | <br>–<br>– | kV/V |
| Output Voltage Swing ($V_{ID}$ = ± 0.2 V)<br>$R_L$ = 10 kΩ<br>$R_L$ = 10 kΩ<br>$R_L$ = 600 Ω<br>$R_L$ = 600 Ω | 8, 9, 10 | <br>$V_{OH}$<br>$V_{OL}$<br>$V_{OH}$<br>$V_{OL}$ | <br>4.85<br>–<br>4.75<br>– | <br>4.95<br>0.05<br>4.85<br>0.15 | <br>–<br>0.15<br>–<br>0.25 | V |
| Common Mode Rejection ($V_{in}$ = 0 V to 5.0 V) | 11 | CMR | 60 | 90 | – | dB |
| Power Supply Rejection Ratio<br>$V_{CC}/V_{EE}$ = 5.0 V/Gnd to 3.0 V/Gnd | 12 | PSRR | <br>500 | <br>25 | <br>– | μV/V |
| Output Short Circuit Current (Source and Sink) | 13, 14 | $I_{SC}$ | 50 | 80 | – | mA |
| Power Supply Current per Amplifier ($V_O$ = 0 V)<br>$T_A$ = – 40° to +105°C<br>$T_A$ = – 55° to +125°C | 15 | $I_D$ | <br>–<br>– | <br>0.9<br>0.9 | <br>1.125<br>1.125 | mA |

**AC ELECTRICAL CHARACTERISTICS** ($V_{CC}$ = + 5.0 V, $V_{EE}$ = Ground, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Figure | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Slew Rate<br>($V_S$ = ± 2.5 V, $V_O$ = – 2.0 V to + 2.0 V, $R_L$ = 2.0 kΩ, $A_V$ = +1.0) | 16, 26 | SR | <br>0.5 | <br>1.0 | <br>– | V/μs |
| Gain Bandwidth Product (f = 100 kHz) | 17 | GBW | – | 2.2 | – | MHz |
| Gain Margin ($R_L$ = 600 Ω, $C_L$ = 0 pF) | 20, 21, 22 | $A_M$ | – | 12 | – | dB |
| Phase Margin ($R_L$ = 600 Ω, $C_L$ = 0 pF) | 20, 21, 22 | $\phi_M$ | – | 65 | – | Deg |
| Channel Separation (f = 1.0 Hz to 20 kHz, $A_V$ = 100) | 23 | CS | – | 90 | – | dB |
| Power Bandwidth ($V_O$ = 4.0 $V_{pp}$, $R_L$ = 600 Ω, THD ≤ 1 %) | | $BW_P$ | – | 28 | – | kHz |
| Total Harmonic Distortion ($R_L$ = 600 Ω, $V_O$ = 1.0 $V_{pp}$, $A_V$ = 1.0)<br>f = 1.0 kHz<br>f = 10 kHz | 24 | THD | <br>–<br>– | <br>0.002<br>0.008 | <br>–<br>– | % |
| Open Loop Output Impedance<br>($V_O$ = 0 V, f = 2.0 MHz, $A_V$ = 10) | | $\lvert Z_O \rvert$ | <br>– | <br>100 | <br>– | Ω |
| Differential Input Resistance ($V_{CM}$ = 0 V) | | $R_{in}$ | – | 200 | – | kΩ |
| Differential Input Capacitance ($V_{CM}$ = 0 V) | | $C_{in}$ | – | 8.0 | – | pF |
| Equivalent Input Noise Voltage ($R_S$ = 100 Ω)<br>f = 10 Hz<br>f = 1.0 kHz | 25 | $e_n$ | <br>–<br>– | <br>25<br>20 | <br>–<br>– | $\frac{nV}{\sqrt{Hz}}$ |
| Equivalent Input Noise Current<br>f = 10 Hz<br>f = 1.0 kHz | 25 | $i_n$ | <br>–<br>– | <br>0.8<br>0.2 | <br>–<br>– | $\frac{pA}{\sqrt{Hz}}$ |

**Figure 1. Circuit Schematic**
(Each Amplifier)




This device contains 70 active transistors (each amplifier).

**Figure 2. Maximum Power Dissipation versus Temperature**

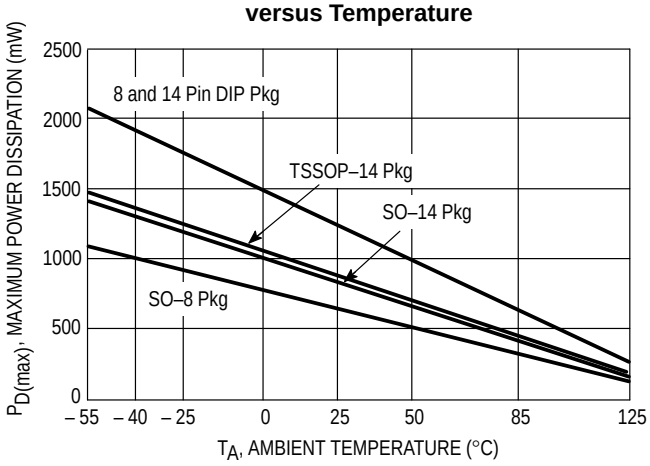



**Figure 3. Input Offset Voltage Distribution**

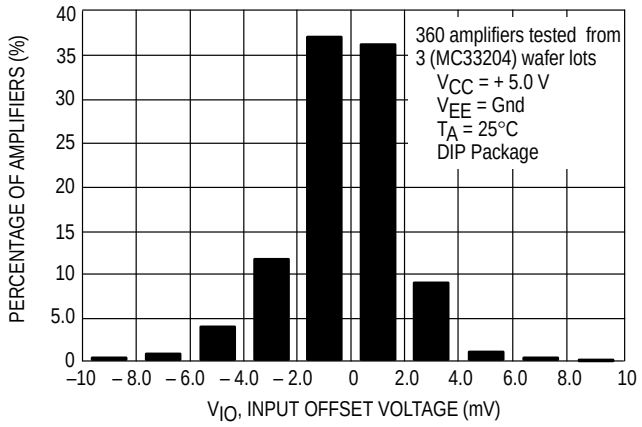



**Figure 4. Input Offset Voltage Temperature Coefficient Distribution**

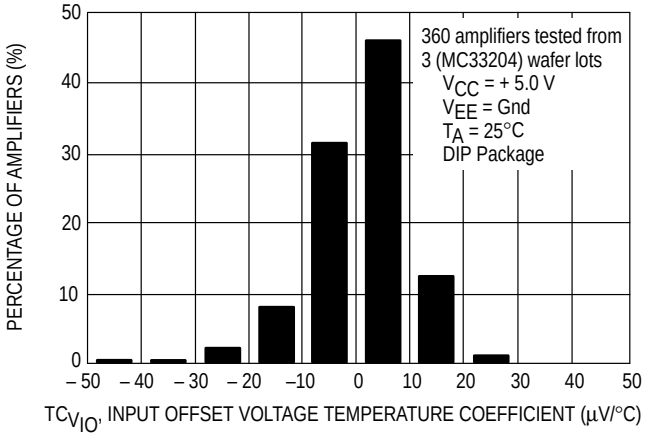



**Figure 5. Input Bias Current versus Temperature**

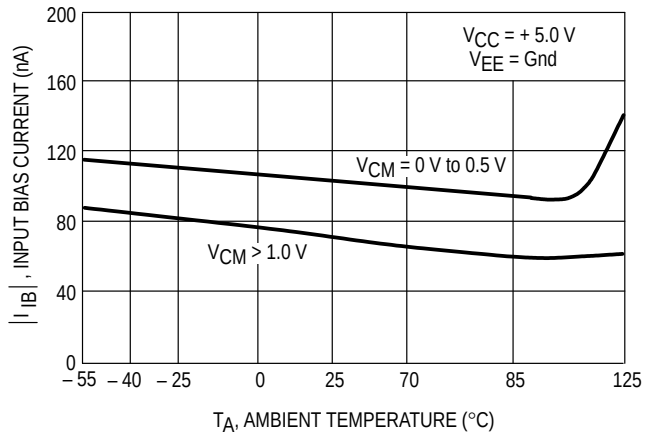



**Figure 6. Input Bias Current versus Common Mode Voltage**

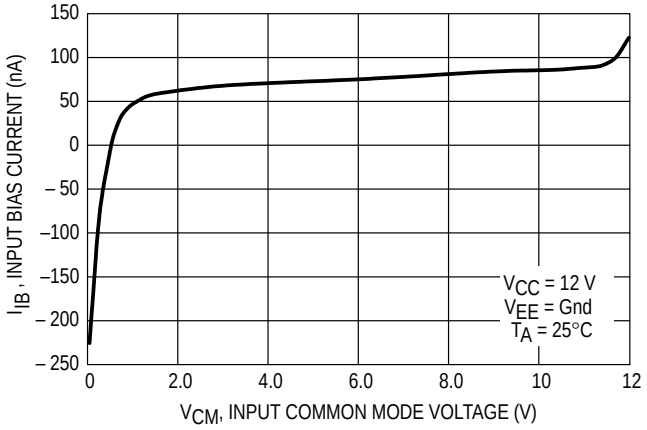



**Figure 7. Open Loop Voltage Gain versus Temperature**

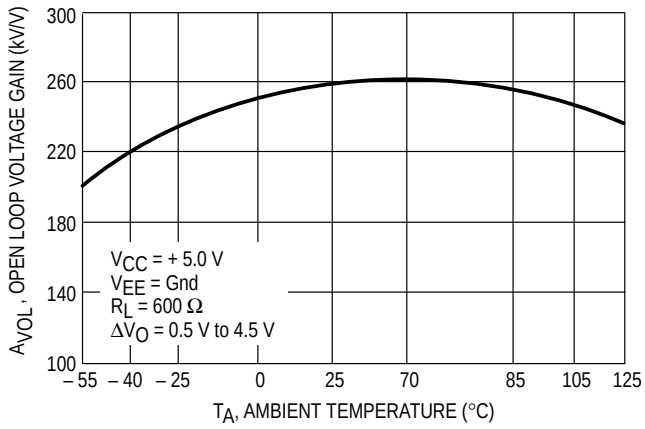


**Figure 8. Output Voltage Swing versus Supply Voltage**

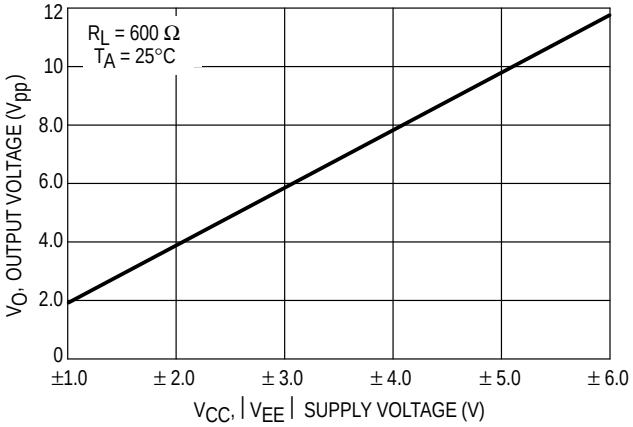



**Figure 9. Output Saturation Voltage versus Load Current**

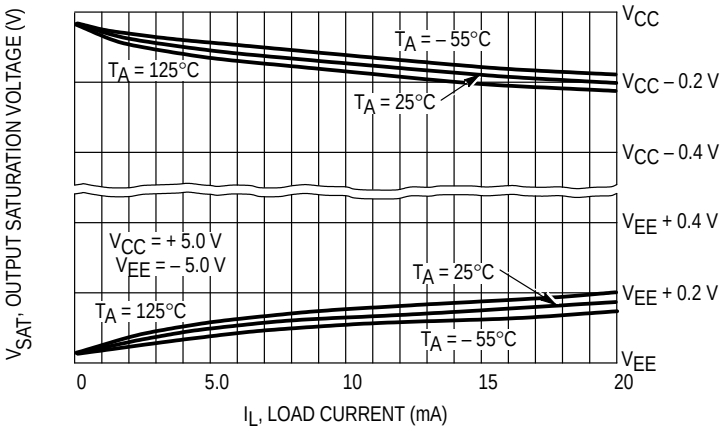



**Figure 10. Output Voltage versus Frequency**

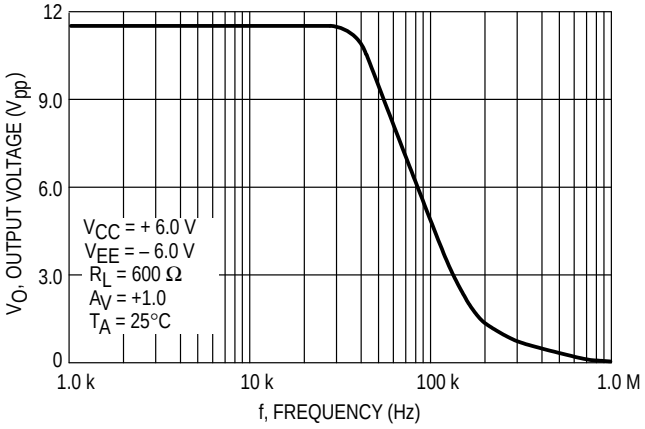



**Figure 11. Common Mode Rejection versus Frequency**

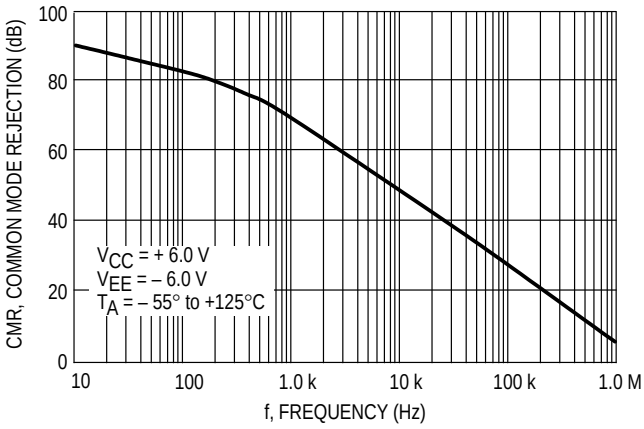



**Figure 12. Power Supply Rejection versus Frequency**

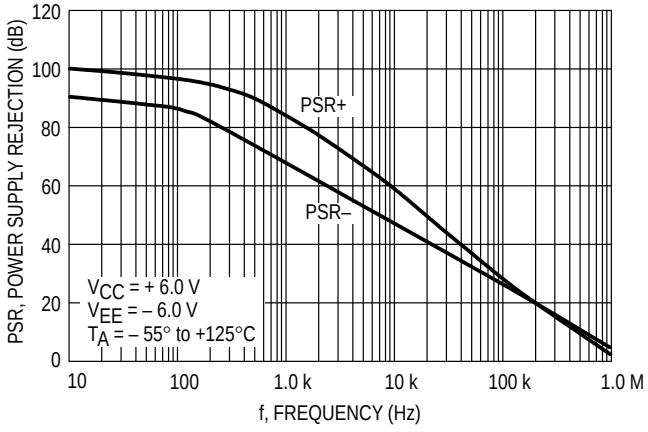



**Figure 13. Output Short Circuit Current versus Output Voltage**

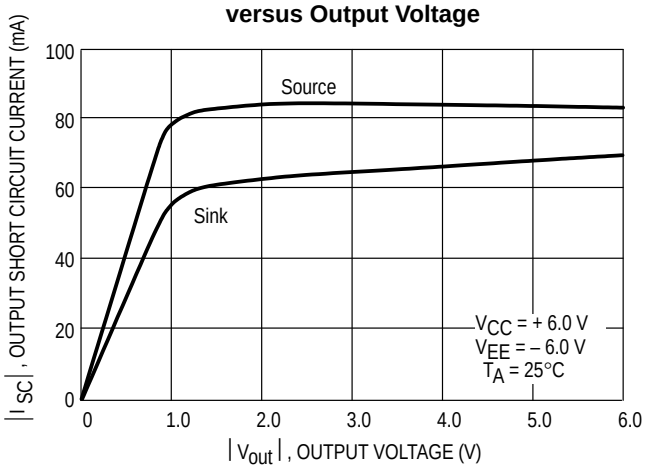


**Figure 14. Output Short Circuit Current versus Temperature**

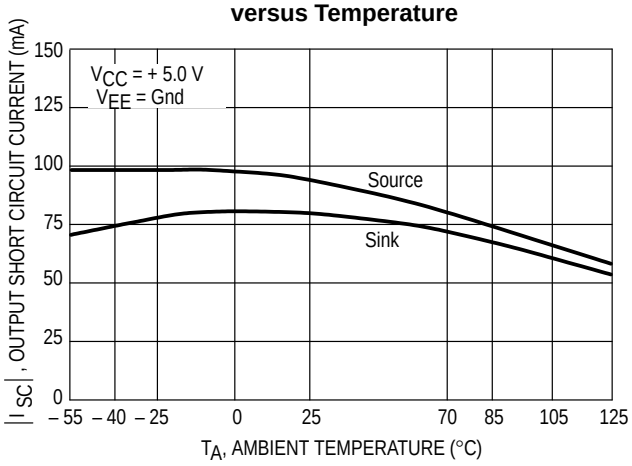



**Figure 15. Supply Current per Amplifier versus Supply Voltage with No Load**

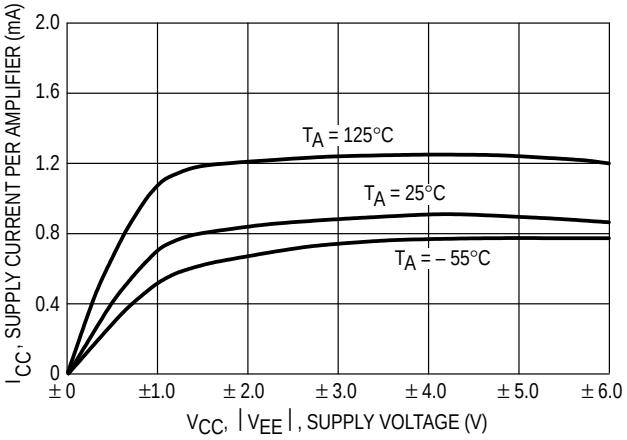



**Figure 16. Slew Rate versus Temperature**

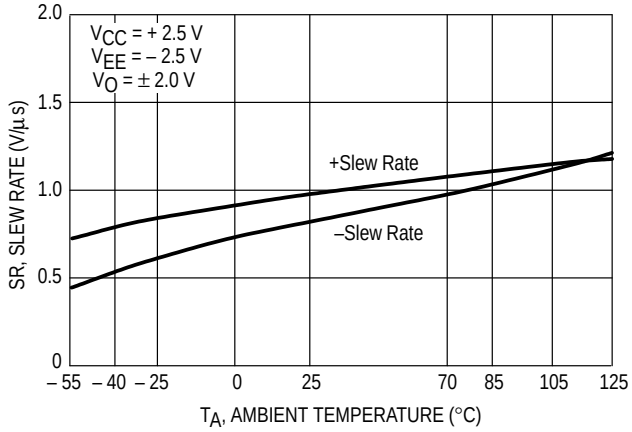



**Figure 17. Gain Bandwidth Product versus Temperature**

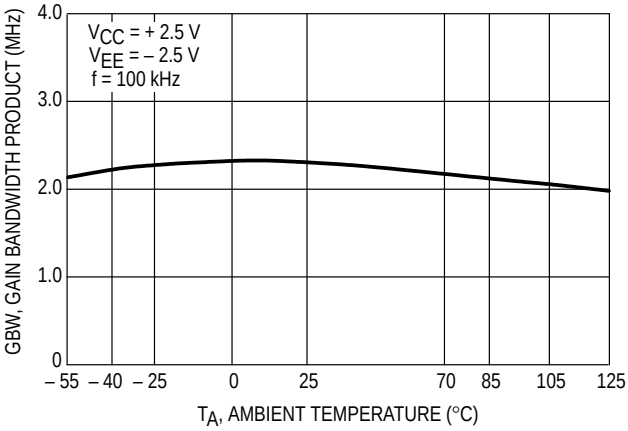



**Figure 18. Voltage Gain and Phase versus Frequency**

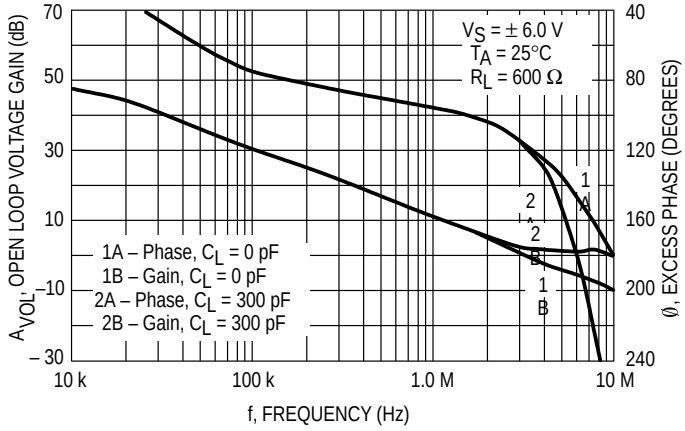



**Figure 19. Voltage Gain and Phase versus Frequency**

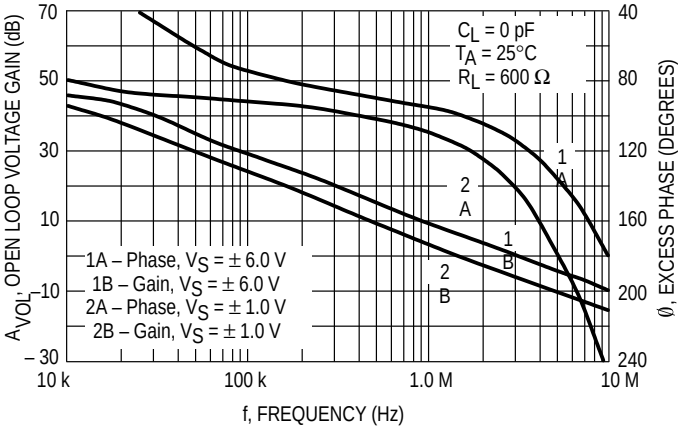


**Figure 20. Gain and Phase Margin versus Temperature**

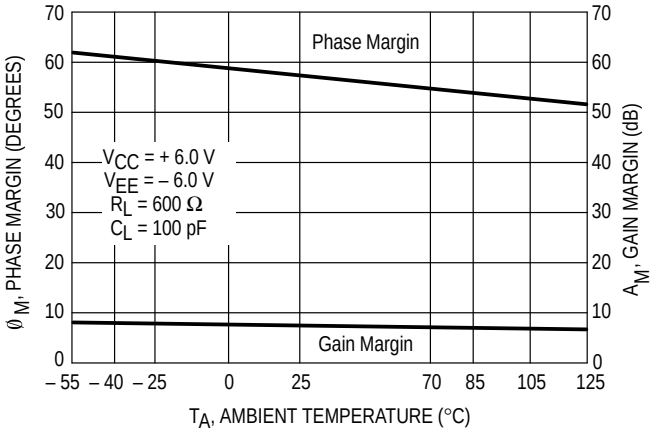



**Figure 21. Gain and Phase Margin versus Differential Source Resistance**

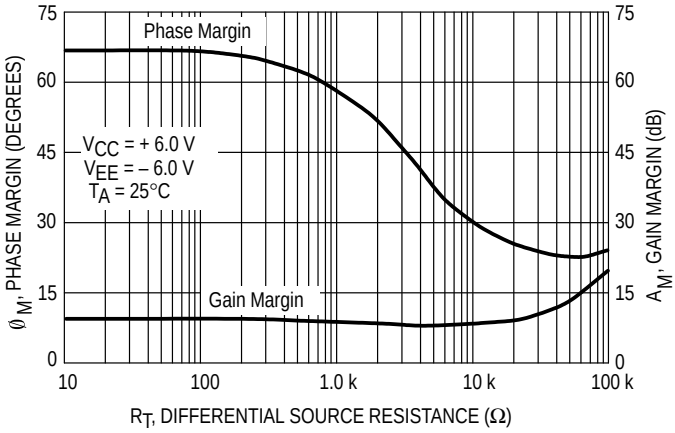



**Figure 22. Gain and Phase Margin versus Capacitive Load**

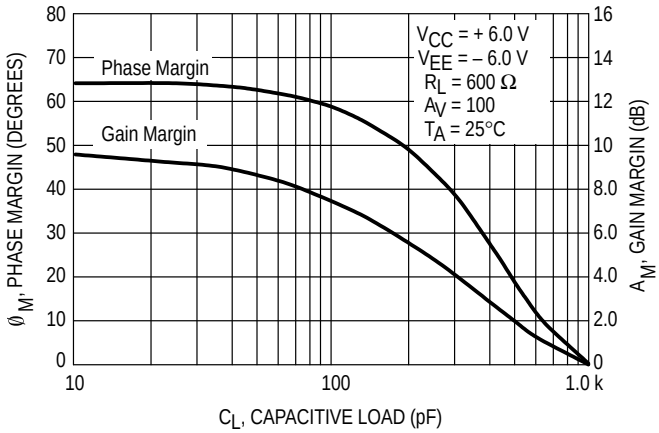



**Figure 23. Channel Separation versus Frequency**

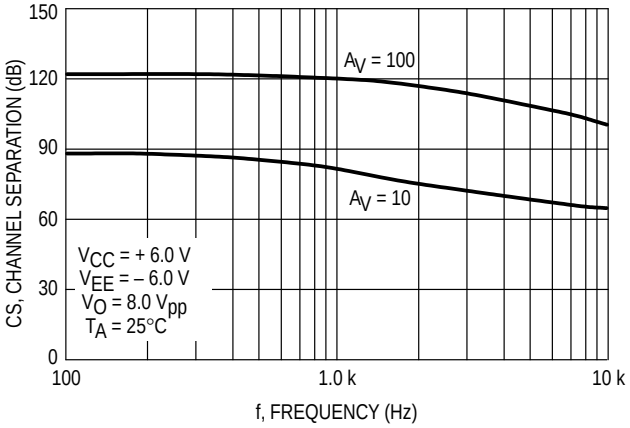



**Figure 24. Total Harmonic Distortion versus Frequency**

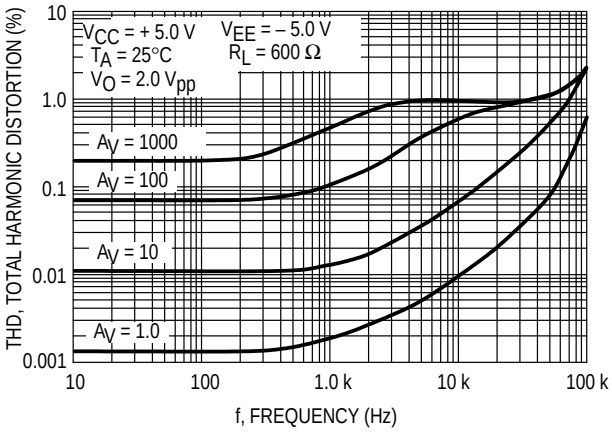
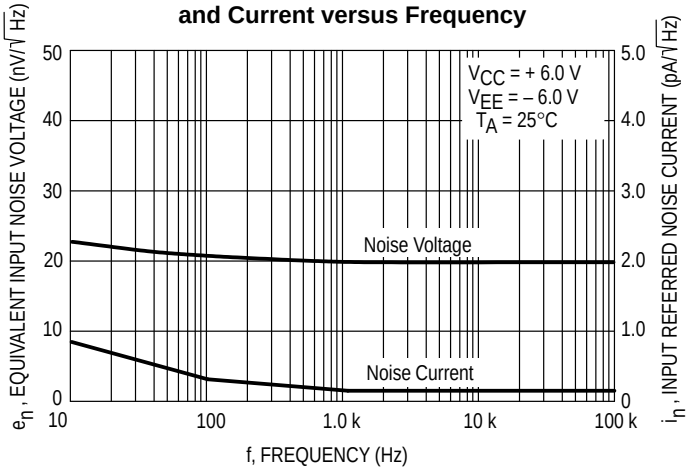



**Figure 25. Equivalent Input Noise Voltage and Current versus Frequency**



## General Information

The MC33201/2/4 family of operational amplifiers are unique in their ability to swing rail–to–rail on both the input and the output with a completely bipolar design. This offers low noise, high output current capability and a wide common mode input voltage range even with low supply voltages. Operation is guaranteed over an extended temperature range and at supply voltages of 2.0 V, 3.3 V and 5.0 V and ground.

Since the common mode input voltage range extends from $V_{CC}$ to $V_{EE}$, it can be operated with either single or split voltage supplies. The MC33201/2/4 are guaranteed not to latch or phase reverse over the entire common mode range, however, the inputs should not be allowed to exceed maximum ratings.

## Circuit Information

Rail–to–rail performance is achieved at the input of the amplifiers by using parallel NPN–PNP differential input stages. When the inputs are within 800 mV of the negative rail, the PNP stage is on. When the inputs are more than 800 mV greater than $V_{EE}$, the NPN stage is on. This switching of input pairs will cause a reversal of input bias currents (see Figure 6). Also, slight differences in offset voltage may be noted between the NPN and PNP pairs. Cross–coupling techniques have been used to keep this change to a minimum.

In addition to its rail–to–rail performance, the output stage is current boosted to provide 80 mA of output current, enabling the op amp to drive 600 Ω loads. Because of this high output current capability, care should be taken not to exceed the 150°C maximum junction temperature.

**Figure 26. Noninverting Amplifier Slew Rate**

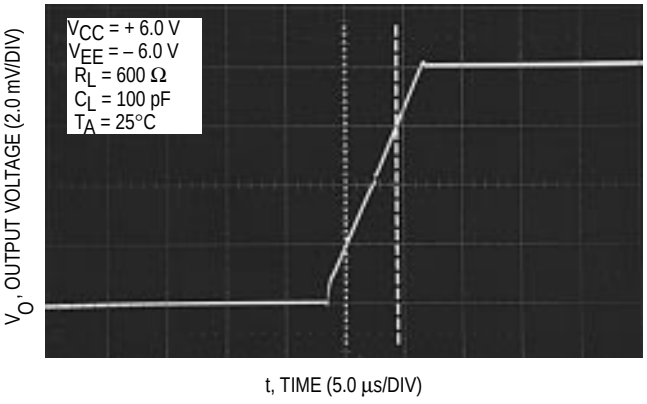



**Figure 27. Small Signal Transient Response**

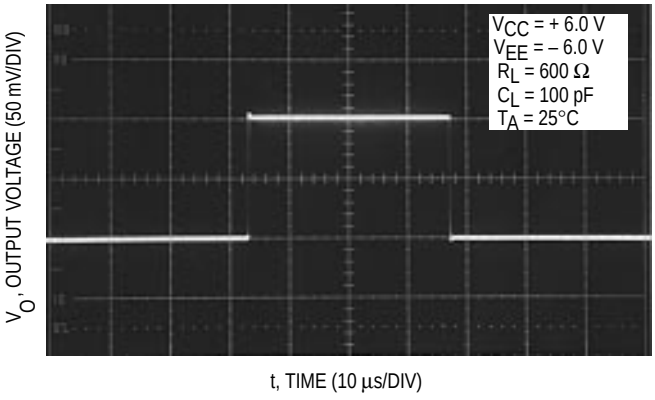
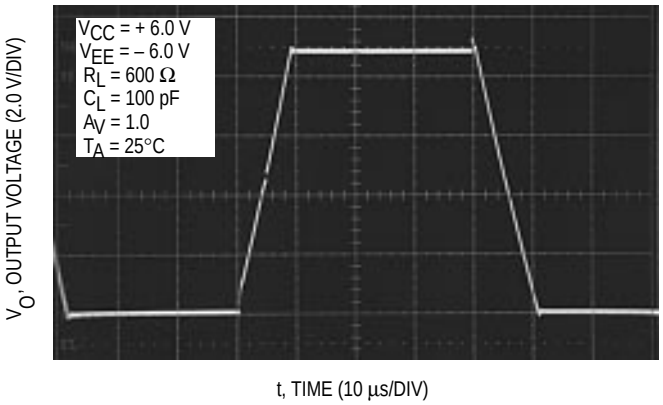



**Figure 28. Large Signal Transient Response**

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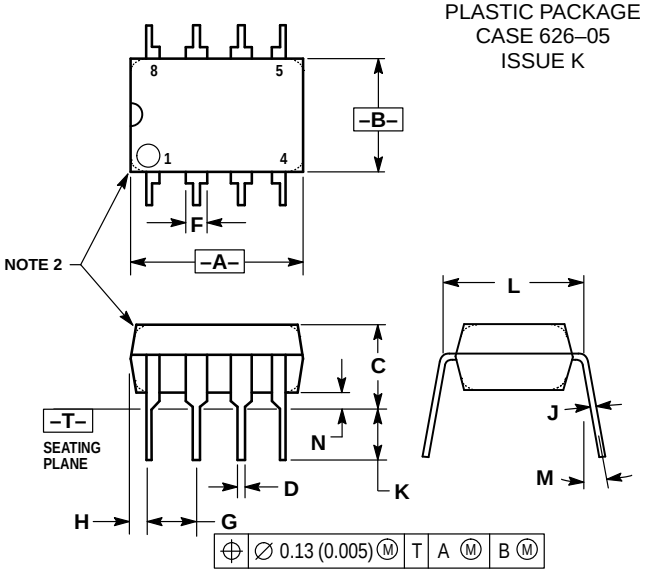
## OUTLINE DIMENSIONS

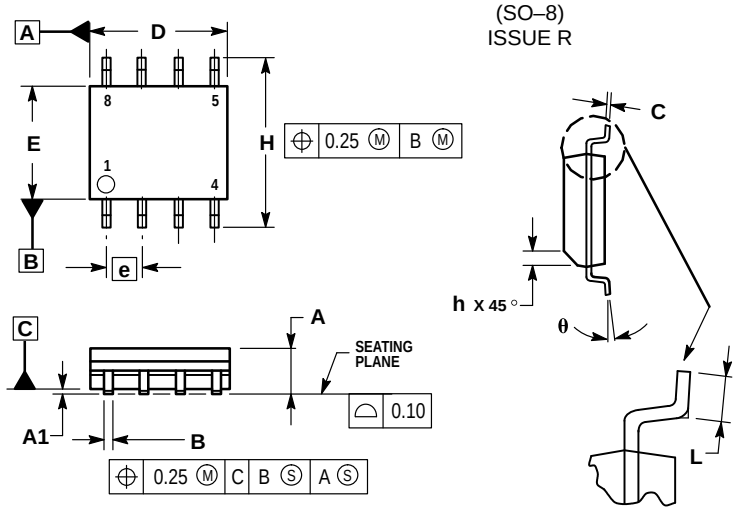
**P SUFFIX**
PLASTIC PACKAGE
CASE 626–05
ISSUE K




NOTES:
1. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
2. PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 9.40 | 10.16 | 0.370 | 0.400 |
| B | 6.10 | 6.60 | 0.240 | 0.260 |
| C | 3.94 | 4.45 | 0.155 | 0.175 |
| D | 0.38 | 0.51 | 0.015 | 0.020 |
| F | 1.02 | 1.78 | 0.040 | 0.070 |
| G | 2.54 BSC | | 0.100 BSC | |
| H | 0.76 | 1.27 | 0.030 | 0.050 |
| J | 0.20 | 0.30 | 0.008 | 0.012 |
| K | 2.92 | 3.43 | 0.115 | 0.135 |
| L | 7.62 BSC | | 0.300 BSC | |
| M | — | 10° | — | 10° |
| N | 0.76 | 1.01 | 0.030 | 0.040 |

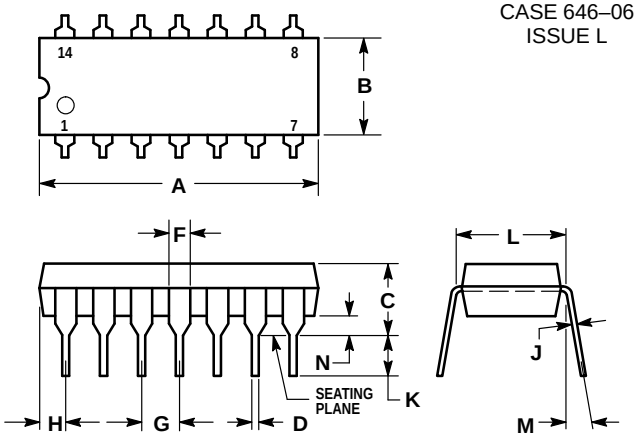
**D SUFFIX**
PLASTIC PACKAGE
CASE 751–05
(SO–8)
ISSUE R




NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. DIMENSIONS ARE IN MILLIMETERS.
3. DIMENSION D AND E DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 PER SIDE.
5. DIMENSION B DOES NOT INCLUDE MOLD PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 TOTAL IN EXCESS OF THE B DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | |
|---|---|---|
| DIM | MIN | MAX |
| A | 1.35 | 1.75 |
| A1 | 0.10 | 0.25 |
| B | 0.35 | 0.49 |
| C | 0.18 | 0.25 |
| D | 4.80 | 5.00 |
| E | 3.80 | 4.00 |
| e | 1.27 BSC | |
| H | 5.80 | 6.20 |
| h | 0.25 | 0.50 |
| L | 0.40 | 1.25 |
| θ | 0° | 7° |

**P SUFFIX**
PLASTIC PACKAGE
CASE 646–06
ISSUE L

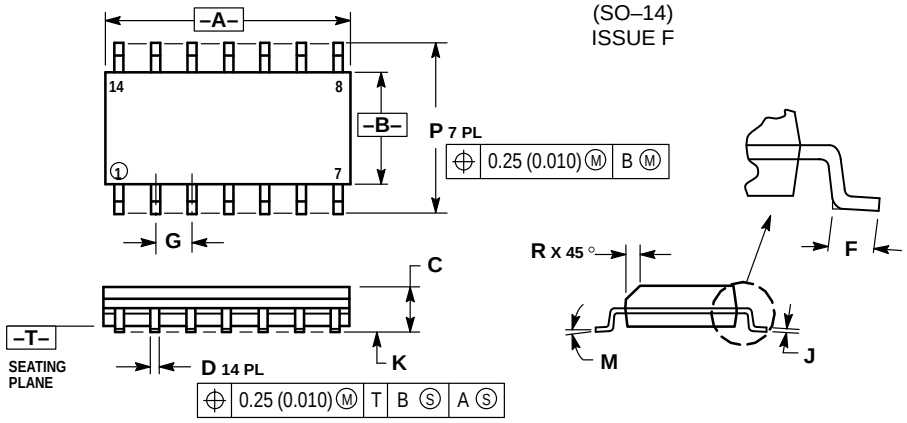



NOTES:
1. LEADS WITHIN 0.13 (0.005) RADIUS OF TRUE POSITION AT SEATING PLANE AT MAXIMUM MATERIAL CONDITION.
2. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
3. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
4. ROUNDED CORNERS OPTIONAL.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 0.715 | 0.770 | 18.16 | 19.56 |
| B | 0.240 | 0.260 | 6.10 | 6.60 |
| C | 0.145 | 0.185 | 3.69 | 4.69 |
| D | 0.015 | 0.021 | 0.38 | 0.53 |
| F | 0.040 | 0.070 | 1.02 | 1.78 |
| G | 0.100 BSC | | 2.54 BSC | |
| H | 0.052 | 0.095 | 1.32 | 2.41 |
| J | 0.008 | 0.015 | 0.20 | 0.38 |
| K | 0.115 | 0.135 | 2.92 | 3.43 |
| L | 0.300 BSC | | 7.62 BSC | |
| M | 0° | 10° | 0° | 10° |
| N | 0.015 | 0.039 | 0.39 | 1.01 |

## OUTLINE DIMENSIONS

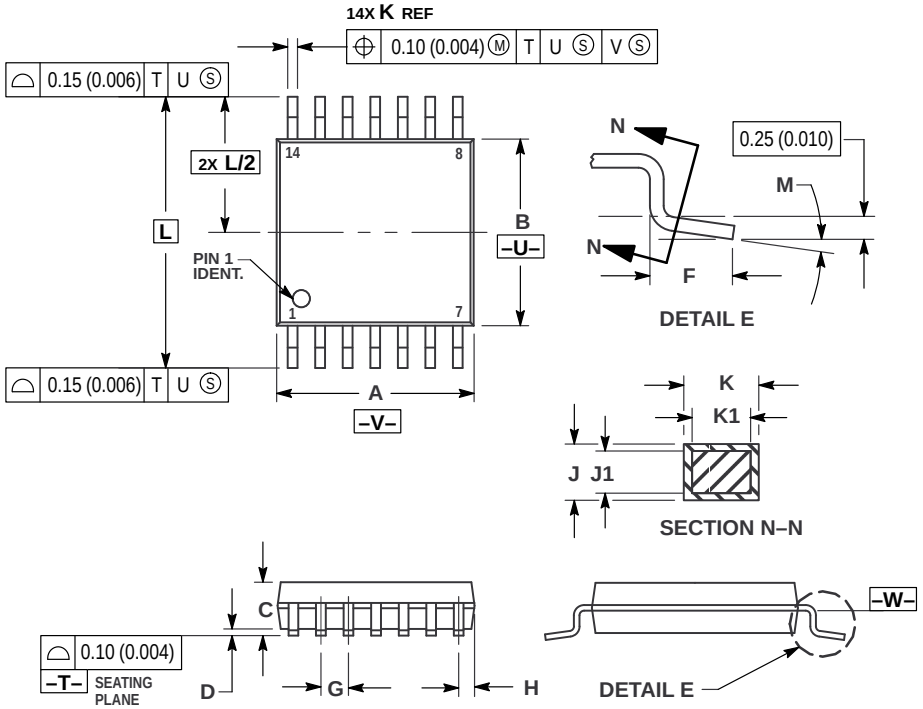
**D SUFFIX**
PLASTIC PACKAGE
CASE 751A–03
(SO–14)
ISSUE F




NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 8.55 | 8.75 | 0.337 | 0.344 |
| B | 3.80 | 4.00 | 0.150 | 0.157 |
| C | 1.35 | 1.75 | 0.054 | 0.068 |
| D | 0.35 | 0.49 | 0.014 | 0.019 |
| F | 0.40 | 1.25 | 0.016 | 0.049 |
| G | 1.27 BSC | | 0.050 BSC | |
| J | 0.19 | 0.25 | 0.008 | 0.009 |
| K | 0.10 | 0.25 | 0.004 | 0.009 |
| M | 0 ° | 7 ° | 0 ° | 7 ° |
| P | 5.80 | 6.20 | 0.228 | 0.244 |
| R | 0.25 | 0.50 | 0.010 | 0.019 |

**DTB SUFFIX**
PLASTIC PACKAGE
CASE 948G–01
(TSSOP–14)
ISSUE O




NOTES:
1 DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2 CONTROLLING DIMENSION: MILLIMETER.
3 DIMENSION A DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH OR GATE BURRS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4 DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.
5 DIMENSION K DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 (0.003) TOTAL IN EXCESS OF THE K DIMENSION AT MAXIMUM MATERIAL CONDITION.
6 TERMINAL NUMBERS ARE SHOWN FOR REFERENCE ONLY.
7 DIMENSION A AND B ARE TO BE DETERMINED AT DATUM PLANE –W–.

| | MILLIMETERS | | INCHES | |
|---|---|---|---|---|
| DIM | MIN | MAX | MIN | MAX |
| A | 4.90 | 5.10 | 0.193 | 0.200 |
| B | 4.30 | 4.50 | 0.169 | 0.177 |
| C | — | 1.20 | — | 0.047 |
| D | 0.05 | 0.15 | 0.002 | 0.006 |
| F | 0.50 | 0.75 | 0.020 | 0.030 |
| G | 0.65 BSC | | 0.026 BSC | |
| H | 0.50 | 0.60 | 0.020 | 0.024 |
| J | 0.09 | 0.20 | 0.004 | 0.008 |
| J1 | 0.09 | 0.16 | 0.004 | 0.006 |
| K | 0.19 | 0.30 | 0.007 | 0.012 |
| K1 | 0.19 | 0.25 | 0.007 | 0.010 |
| L | 6.40 BSC | | 0.252 BSC | |
| M | 0 ° | 8 ° | 0 ° | 8 ° |

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