# 20MHz Bandwidth, Low Noise CMOS Op-amps

## Features

- **Gain-bandwidth Product: 20MHz**
- **Low Noise: 7.3nV/√Hz(f= 1kHz)**
- **Slew Rate: 25 V/μs**
- **Offset Voltage: 1 mV (max)**
- **Low THD+N: 0.0005%**
- **Supply Range: 2.2V to 5.5V**
- **Supply Current: 3.5 mA/ch**
- **Low Input Bias Current: 0.3pA Typical**
- **Rail-to-Rail I/O**
- **High Output Current: 70mA (1.0V Drop)**
- **–40°C to 125°C Operation Range**

## Applications

- Sensor Signal Conditioning
- Consumer Audio
- Multi-Pole Active Filters
- Control-Loop Amplifiers
- Communications
- Security
- Scanners

## Description

The TP240x series consists of single, dual, and quad-channel CMOS operational amplifiers featuring low noise and rail-to-rail inputs/outputs optimized for low-power, single-supply applications. Specified over a wide supply range of 2.2 V to 5.5 V, the low quiescent current of only 3.5 mA per channel makes these devices well-suited for power-sensitive applications.

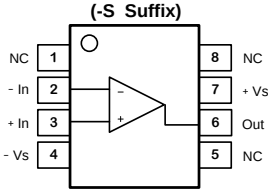
The combination of very low noise (7.3 nV/ √ Hz at 1 kHz), high gain-bandwidth (20 MHz), and fast slew rate (25 V/μs) make the TP240x family ideal for a wide range of applications, including signal conditioning and sensor amplification requiring high gains. Featuring low THD+N, the TP240x series is also excellent for consumer audio applications, particularly for single-supply systems.

The TP2401 is single channel version available in 8-pin SOIC and 5-pin SOT23 packages. The TP2402 is dual channel version available in 8-pin SOIC and MSOP packages. The TP2404 is quad channel version available in 14-pin SOIC and TSSOP packages.

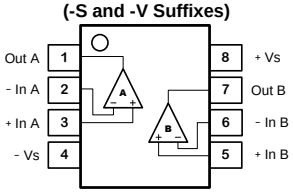


## Pin Configuration (Top View)

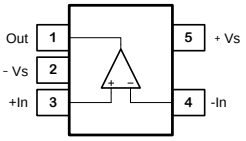
**TP2401**
**8-Pin SOIC**
**(-S Suffix)**



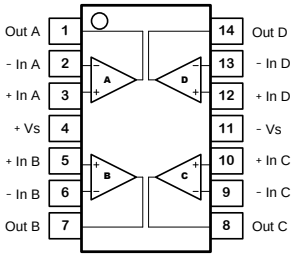

**TP2402**
**8-Pin SOIC/MSOP**
**(-S and -V Suffixes)**



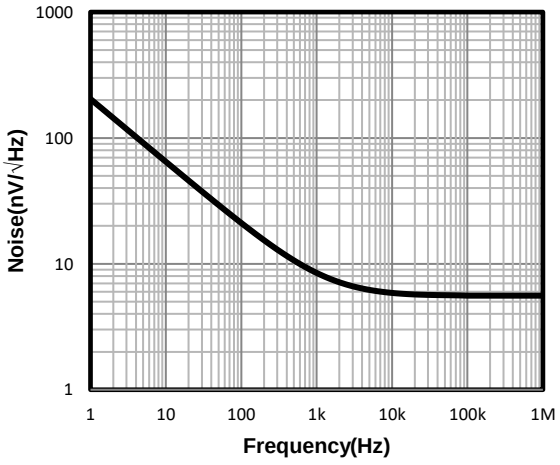

**TP2401**
**5-Pin SOT23**
**(-T Suffix)**




**TP2404**
**14-Pin SOIC/TSSOP**
**(-S and -T Suffixes)**




**Input Voltage Noise Spectral Density**



## Order Information

| Order Number | Package | Transport Media, Quantity | Marking Information |
|---|---|---|---|
| TP2402-SR | 8-Pin SOIC | Tape and Reel, 4,000 | TP2402 |
| TP2402-VR | 8-Pin MSOP | Tape and Reel, 3,000 | TP2402 |
| TP2404-TR | 14-Pin TSSOP | Tape and Reel, 3,000 | TP2404 |

## Absolute Maximum Ratings Note 1

Supply Voltage: $V^+ – V^-$ Note 2.....7.0V
Input Voltage..... $V^-$ – 0.3 to $V^+$ + 0.3
Input Current: +IN, –IN Note 3..... ±20mA
Output Current: OUT..... ±160mA
Output Short-Circuit Duration Note 4..... Infinite

Current at Supply Pins……..... ±60mA
Operating Temperature Range.....–40°C to 125°C
Maximum Junction Temperature..... 150°C
Storage Temperature Range..... –65°C to 150°C
Lead Temperature (Soldering, 10 sec) ..... 260°C

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** The op amp supplies must be established simultaneously, with, or before, the application of any input signals.

**Note 3:** The inputs are protected by ESD protection diodes to each power supply. If the input extends more than 500mV beyond the power supply, the input current should be limited to less than 10mA.

**Note 4**: A heat sink may be required to keep the junction temperature below the absolute maximum. This depends on the power supply voltage and how many amplifiers are shorted. Thermal resistance varies with the amount of PC board metal connected to the package. The specified values are for short traces connected to the leads.

## ESD, Electrostatic Discharge Protection

| Symbol | Parameter | Condition | Minimum Level | Unit |
|---|---|---|---|---|
| HBM | Human Body Model ESD | ANSI/ESDA/JEDEC JS-001 | 6 | kV |
| CDM | Charged Device Model ESD | ANSI/ESDA/JEDEC JS-002 | 2 | kV |

## Thermal Resistance

| Package Type | $\theta_{JA}$ | $\theta_{JC}$ | Unit |
|---|---|---|---|
| 5-Pin SOT23 | 250 | 81 | °C/W |
| 8-Pin SOIC | 158 | 43 | °C/W |
| 8-Pin MSOP | 210 | 45 | °C/W |
| 14-Pin SOIC | 120 | 36 | °C/W |
| 14-Pin TSSOP | 180 | 35 | °C/W |

## Electrical Characteristics

**The specifications are at $T_A$ = 27°C. $V_S$ = +2.2 V to +5.5 V, or ±1.1 V to ±2.75 V, $R_L$ = 2kΩ, $C_L$ =100pF.Unless otherwise noted.**

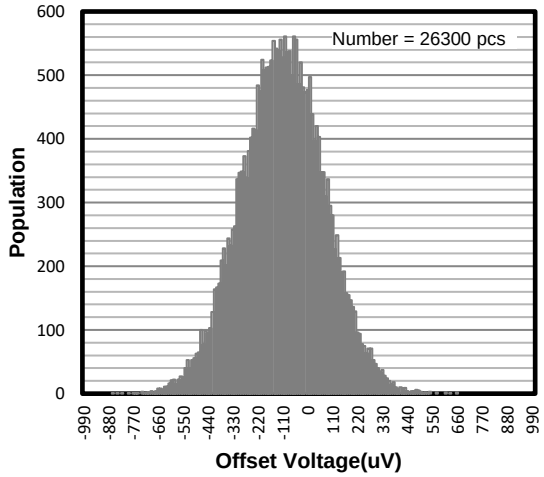
| SYMBOL | PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| $V_{OS}$ | Input Offset Voltage | $V_{CM} = V_{DD}/2$ | -1 | ±0.3 | +1 | mV |
| $V_{OS}$ TC | Input Offset Voltage Drift | -40°C to 125°C | | 1 | 2 | µV/°C |
| $I_B$ | Input Bias Current | $T_A$ = 27 °C | | 0.3 | | pA |
| | | $T_A$ = 85 °C | | 150 | | pA |
| | | $T_A$ = 125 °C | | 300 | | pA |
| $I_{OS}$ | Input Offset Current | | | 0.001 | | pA |
| $V_n$ | Input Voltage Noise | f = 0.1Hz to 10Hz | | 2.0 | | $\mu V_{PP}$ |
| $e_n$ | Input Voltage Noise Density | f = 1kHz | | 7.3 | | nV/√Hz |
| $i_n$ | Input Current Noise | f = 1kHz | | 2 | | fA/√Hz |
| $C_{IN}$ | Input Capacitance | Differential<br>Common Mode | | 7.76<br>6.87 | | pF |
| CMRR | Common Mode Rejection Ratio | $V_{CM}$ = 2V to 3V | 80 | 100 | | dB |
| $V_{CM}$ | Common-mode Input Voltage Range | | $V^-$ -0.3 | | $V^+$+0.3 | V |
| PSRR | Power Supply Rejection Ratio | $V_{CM}$ = 2.5V, $V_S$ = 4V to 5V | 80 | 100 | | dB |
| $A_{VOL}$ | Open-Loop Large Signal Gain | $R_{LOAD}$ = 2kΩ | 100 | 130 | | dB |
| $V_{OL}$, $V_{OH}$ | Output Swing from Supply Rail | $R_{LOAD}$ = 2kΩ | | 13 | 20 | mV |
| $R_{OUT}$ | Closed-Loop Output Impedance | G = 1, f =1MHz, $I_{OUT}$ = 0 | | 0.043 | | Ω |
| $R_O$ | Open-Loop Output Impedance | f = 1kHz, $I_{OUT}$ = 0 | | 125 | | Ω |
| $I_{SC}$ | Output Short-Circuit Current | Sink or source current | 110 | 130 | 200 | mA |
| $V_{DD}$ | Supply Voltage | | 2.2 | | 5.5 | V |
| $I_Q$ | Quiescent Current per Amplifier | $V_{DD}$ = 5V | | 3.5 | 5 | mA |
| PM | Phase Margin | $R_{LOAD}$ = 1kΩ, $C_{LOAD}$ = 60pF | | 60 | | ° |
| GM | Gain Margin | $R_{LOAD}$ = 1kΩ, $C_{LOAD}$ = 60pF | | 11 | | dB |
| GBWP | Gain-Bandwidth Product | f = 1kHz | | 20 | | MHz |
| SR | Slew Rate | AV = 1, $V_{OUT}$ = 1.5V to 3.5V, $C_{LOAD}$ = 60pF, $R_{LOAD}$ = 1kΩ | 18 | 25 | | V/µs |
| FPBW | Full Power Bandwidth Note 1 | | | 5.21 | | MHz |
| $t_S$ | Settling Time, 0.1%<br>Settling Time, 0.01% | AV = –1, 1V Step | | 0.29<br>0.45 | | µs |
| THD+N | Total Harmonic Distortion and Noise | f = 1kHz, AV =1, RL = 2kΩ, VOUT = 1Vp-p | | 123 | | dB |
| $X_{talk}$ | Channel Separation | f = 1kHz, $R_L$ = 2kΩ | | 110 | | dB |

**Note 1:** Full power bandwidth is calculated from the slew rate FPBW = SR/π • $V_{P-P}$

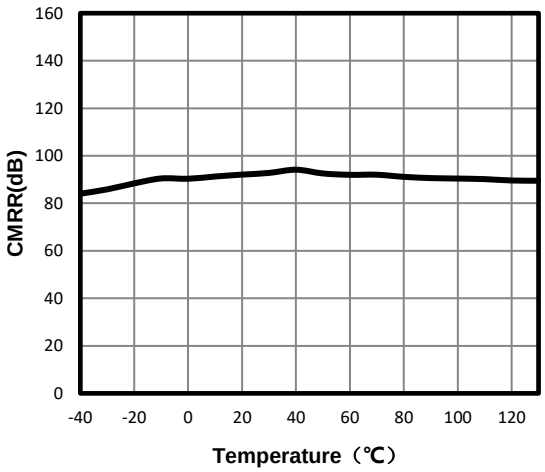
## Typical Performance Characteristics

$V_S$ = ±2.5V, $V_{CM}$ = 0V, $R_L$ = Open, unless otherwise specified.

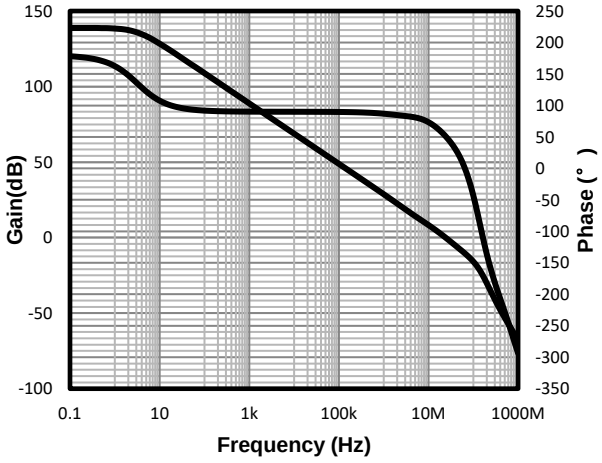
**Offset Voltage Production Distribution**



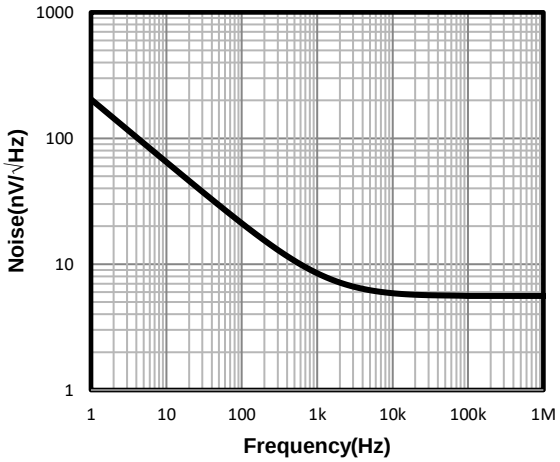

**CMRR vs. Temperature**



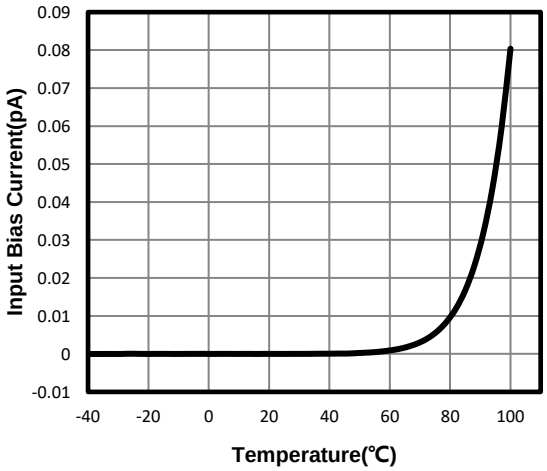

**Open-Loop Gain and Phase**



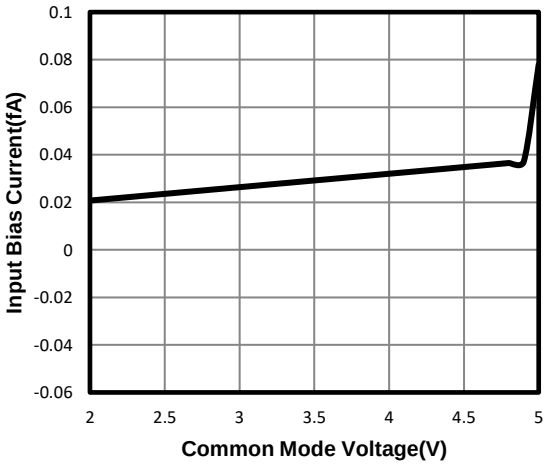

**Input Voltage Noise Spectral Density**




**Input Bias Current vs. Temperature**



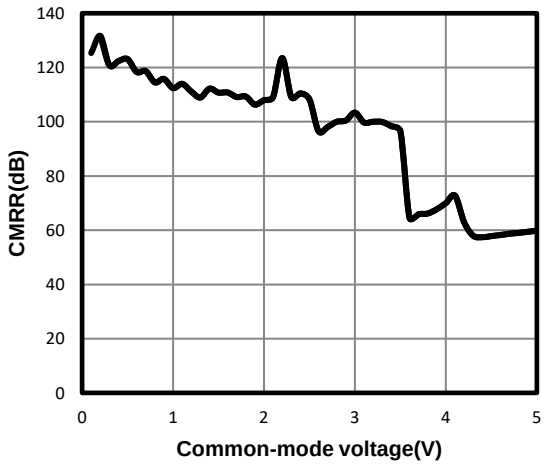

**Input Bias Current vs. Input Common Mode Voltage**



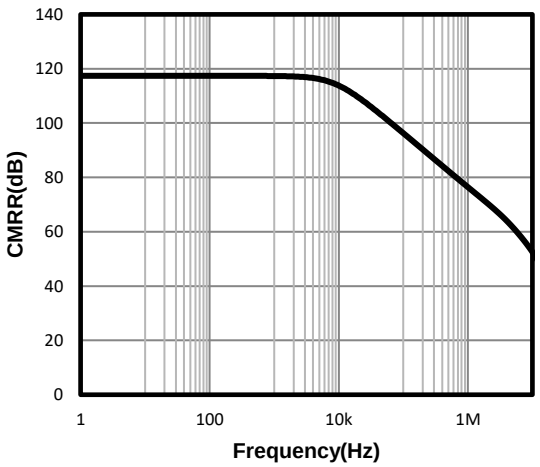
## Typical Performance Characteristics

$V_S$ = ±2.5V, $V_{CM}$ = 0V, $R_L$ = Open, unless otherwise specified. (Continued)

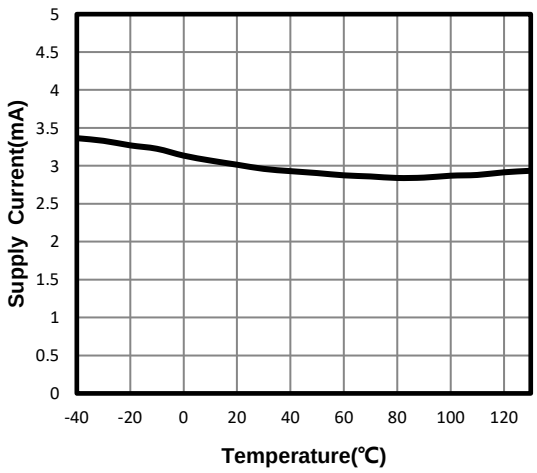
**Common Mode Rejection Ratio**



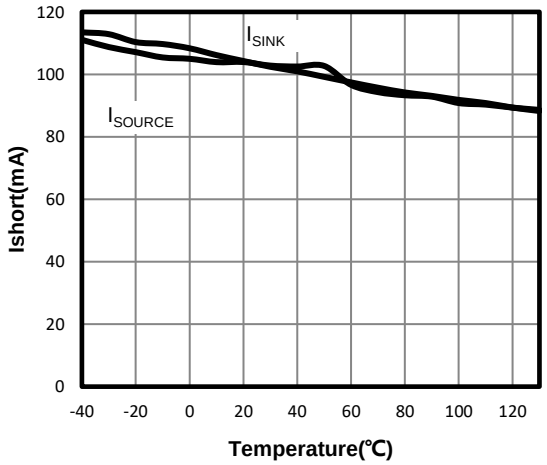

**CMRR vs. Frequency**



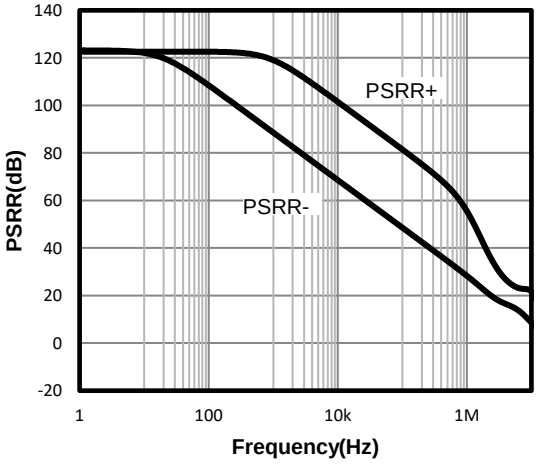

**Quiescent Current vs. Temperature**



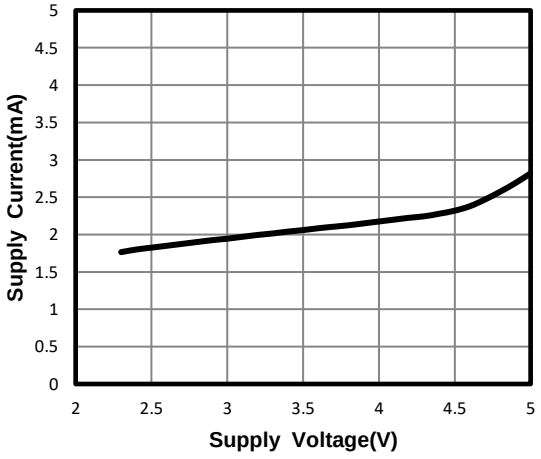

**Short Circuit Current vs. Temperature**




**Power-Supply Rejection Ratio**



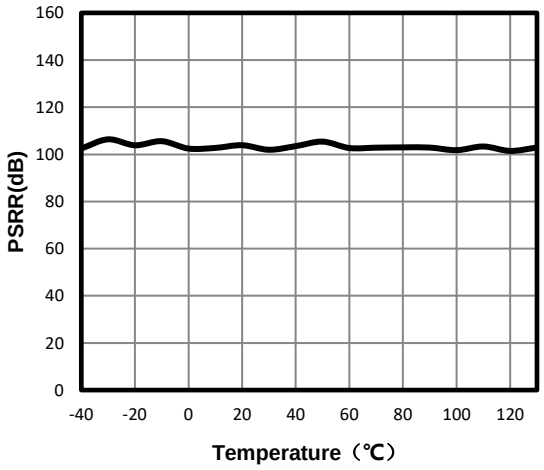

**Quiescent Current vs. Supply Voltage**



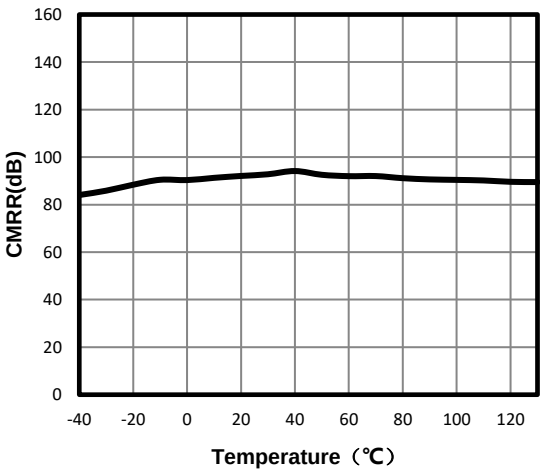
## Typical Performance Characteristics

$V_S$ = ±2.5V, $V_{CM}$ = 0V, $R_L$ = Open, unless otherwise specified. (Continued)

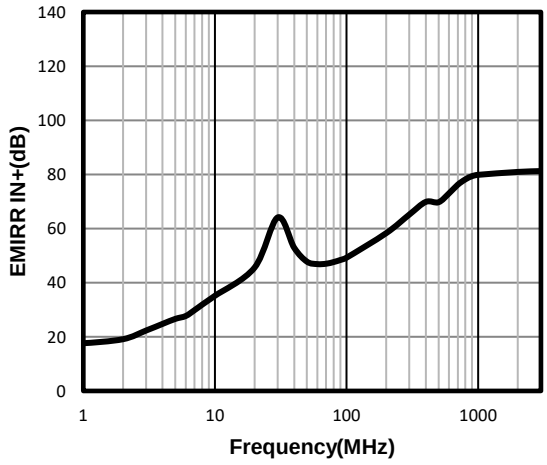
**Power-Supply Rejection Ratio vs. Temperature**



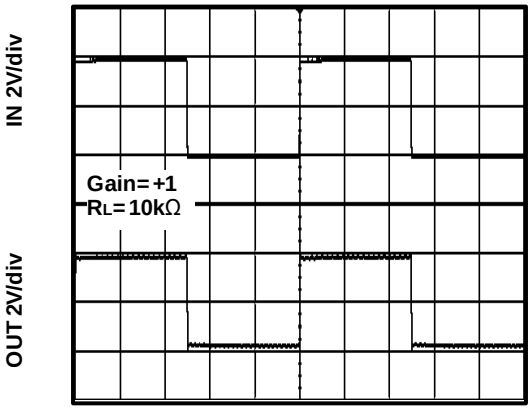

**CMRR vs. Temperature**



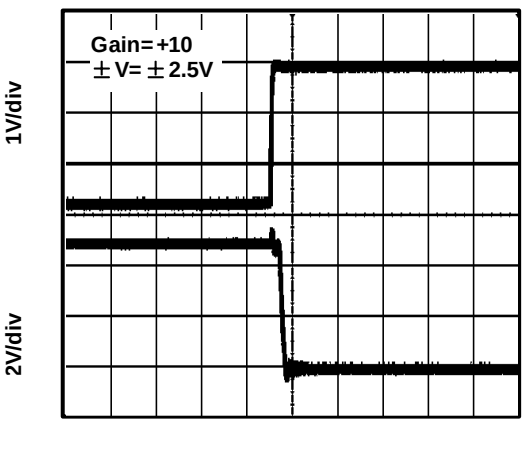

**EMIRR IN+ vs. Frequency**



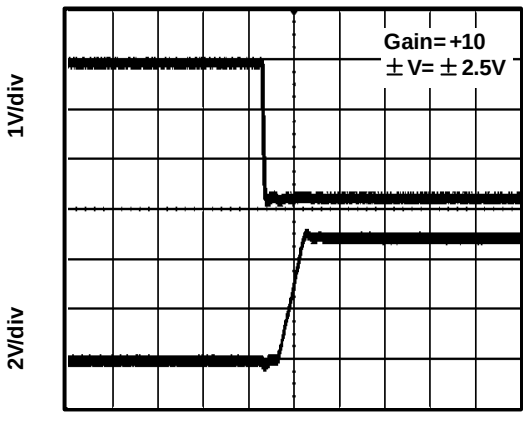

**Large-Scale Step Response**




**Negative Over-Voltage Recovery**



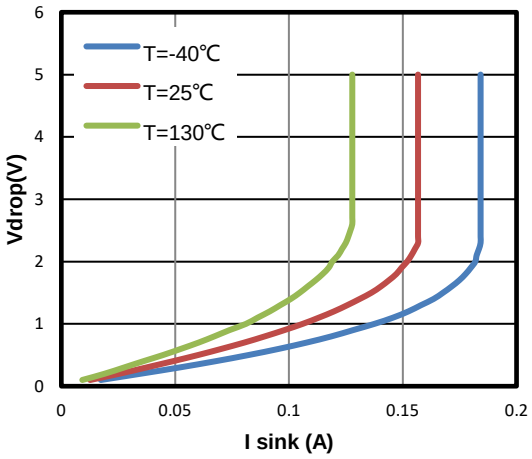

**Positive Over-Voltage Recovery**



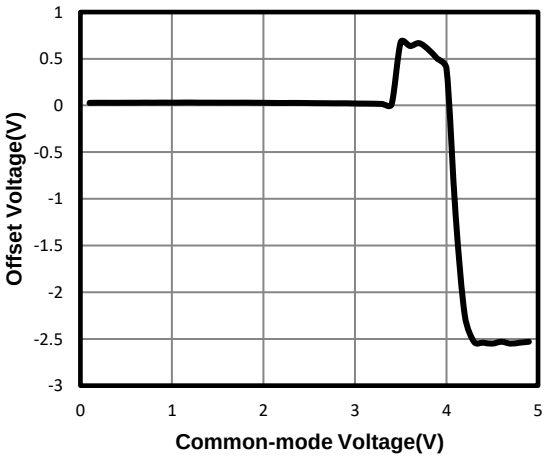
## Typical Performance Characteristics

$V_S$ = ±2.5V, $V_{CM}$ = 0V, $R_L$ = Open, unless otherwise specified. (Continued)

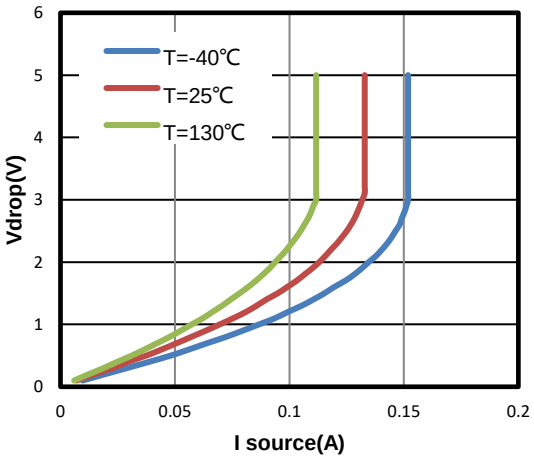
**Negative Output Swing vs. Load Current**




**Offset Voltage vs Common-Mode Voltage**




**Positive Output Swing vs. Load Current**



## Pin Functions

**-IN:** Inverting Input of the Amplifier.

**+IN:** Non-Inverting Input of Amplifier.

**OUT:** Amplifier Output. The voltage range extends to within mV of each supply rail.

**V+ or +Vs:** Positive Power Supply. Typically the voltage is from 2.2V to 5.5V. Split supplies are possible as long as the voltage between V+ and V– is between 2.2V and 5.5V. A bypass capacitor of 0.1μF as close to the part as possible should be used between power supply pins or between supply pins and ground.

**V- or -Vs:** Negative Power Supply. It is normally tied to ground. It can also be tied to a voltage other than ground as long as the voltage between $V_+$ and $V_-$ is from 2.2V to 5.5V. If it is not connected to ground, bypass it with a capacitor of 0.1μF as close to the part as possible.

## Operation

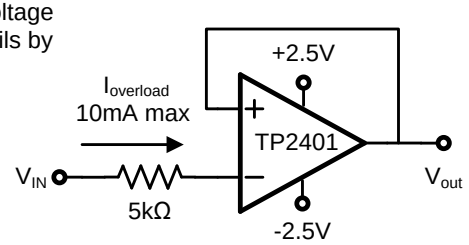
The TP2401 series op amps can operate on a single-supply voltage (2.2 V to 5.5 V), or a split-supply voltage (±1.1 V to ±2.75 V), making them highly versatile and easy to use. The power-supply pins should have local bypass ceramic capacitors (typically 0.001 μF to 0.1 μF). These amplifiers are fully specified from +2.2 V to +5.5 V and over the extended temperature range of –40°C to +125°C. Parameters that can exhibit variance with regard to operating voltage or temperature are presented in the Typical Characteristics

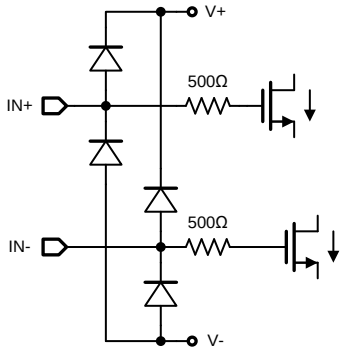
## Applications Information

### Input ESD Diode Protection

The TP2401 incorporates internal electrostatic discharge (ESD) protection circuits on all pins. In the case of input and output pins, this protection primarily consists of current-steering diodes connected between the input and power-supply pins. These ESD protection diodes also provide in-circuit input overdrive protection, as long as the current is limited to 10 mA as stated in the Absolute Maximum Ratings table. Many input signals are inherently current-limited to less than 10 mA; therefore, a limiting resistor is not required. Figure 1 shows how a series input resistor (RS) may be added to the driven input to limit the input current. The added resistor contributes thermal noise at the amplifier input and the value should be kept to the minimum in noise-sensitive applications.

Current-limiting resistor required if input voltage exceeds supply rails by >0.5V.




INPUT ESD DIODE CURRENT LIMITING- UNITY GAIN

**Figure1. Input ESD Diode**

## PHASE REVERSAL

The TP2401 op amps are designed to be immune to phase reversal when the input pins exceed the supply voltages, therefore providing further in-system stability and predictability. Figure 2 shows the input voltage exceeding the supply voltage without any phase reversal.

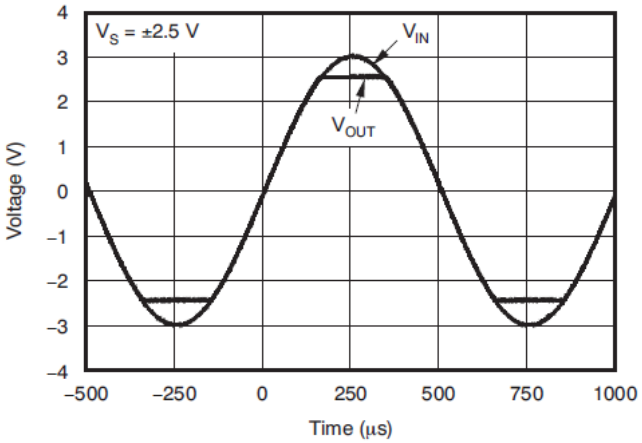



**Figure 2. No Phase Reversal**

## EMI SUSCEPTIBILITY AND INPUT FILTERING

Operational amplifiers vary in susceptibility to electromagnetic interference (EMI). If conducted EMI enters the device, the dc offset observed at the amplifier output may shift from the nominal value while EMI is present. This shift is a result of signal rectification associated with the internal semiconductor junctions. While all operational amplifier pin functions can be affected by EMI, the input pins are likely to be the most susceptible. The TP2401 operational amplifier family incorporates an internal input low-pass filter that reduces the amplifier response to EMI. Both common-mode and differential mode filtering are provided by the input filter. The filter is designed for a cutoff frequency of approximately 400 MHz (–3 dB), with a roll-off of 20 dB per decade.

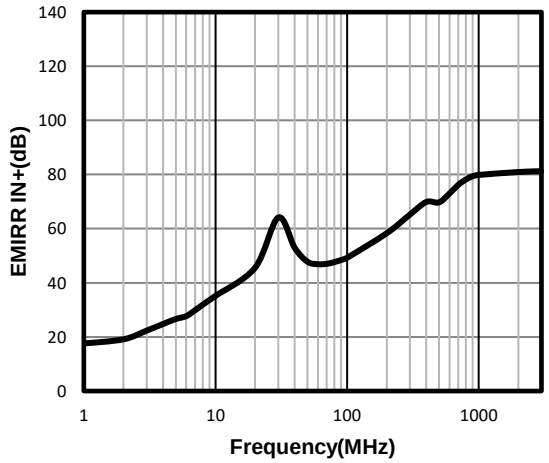



**Figure 3. TP2401 EMIRR IN+ vs Frequency**

## ACTIVE FILTER

The TP2401 is well-suited for active filter applications that require a wide bandwidth, fast slew rate, low-noise, single-supply operational amplifier. Figure 4 shows a 20-kHz, second-order, low-pass filter using the multiplefeedback (MFB) topology. The components have been selected to provide a maximally-flat Butterworth response. Beyond the cutoff frequency, roll-off is –40 dB/dec. The Butterworth response is ideal for applications that require predictable gain characteristics, such as the anti-aliasing filter used in front of an ADC.

One point to observe when considering the MFB filter is that the output is inverted, relative to the input. If this inversion is not required, or not desired, a noninverting output can be achieved through one of these options:

1. adding an inverting amplifier;
2. adding an additional second-order MFB stage

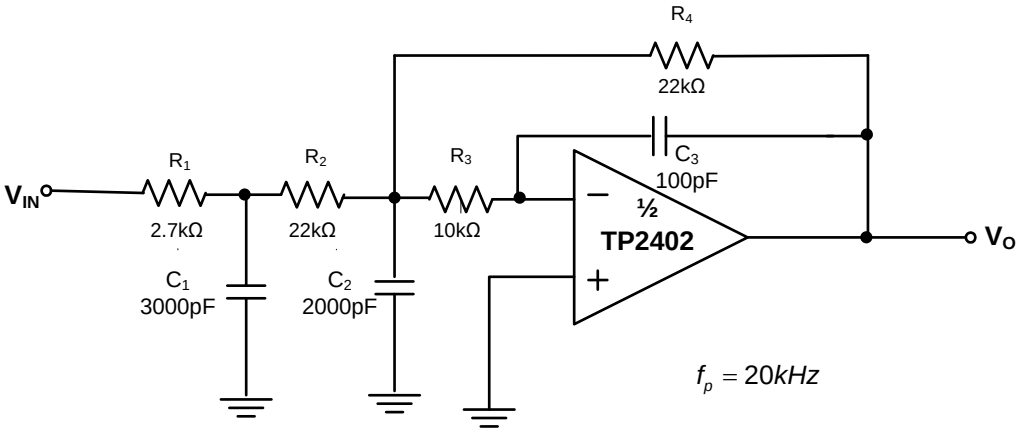



**Figure 4. TP2402 Configured as a Three-Pole, 20-kHz, Sallen-Key Filter**

## PCB Surface Leakage

In applications where low input bias current is critical, Printed Circuit Board (PCB) surface leakage effects need to be considered. Surface leakage is caused by humidity, dust or other contamination on the board. Under low humidity conditions, a typical resistance between nearby traces is $10^{12}\Omega$. A 5V difference would cause 5pA of current to flow, which is greater than the TP2401/2402/2404 OPA's input bias current at +27°C (±3pA, typical). It is recommended to use multi-layer PCB layout and route the OPA's -IN and +IN signal under the PCB surface.

The effective way to reduce surface leakage is to use a guard ring around sensitive pins (or traces). The guard ring is biased at the same voltage as the sensitive pin. An example of this type of layout is shown in Figure 1 for Inverting Gain application.

1. For Non-Inverting Gain and Unity-Gain Buffer:
   a) Connect the non-inverting pin ($V_{IN}$+) to the input with a wire that does not touch the PCB surface.
   b) Connect the guard ring to the inverting input pin ($V_{IN}$–). This biases the guard ring to the Common Mode input voltage.
2. For Inverting Gain and Trans-impedance Gain Amplifiers (convert current to voltage, such as photo detectors):
   a) Connect the guard ring to the non-inverting input pin ($V_{IN}$+). This biases the guard ring to the same reference voltage as the op-amp (e.g., $V_{DD}$/2 or ground).
   b) Connect the inverting pin ($V_{IN}$–) to the input with a wire that does not touch the PCB surface.

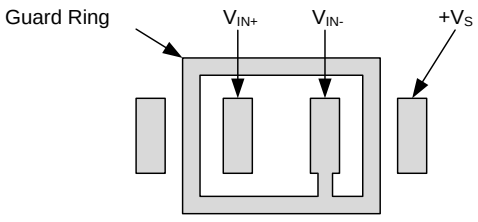



**Figure 5 The Layout of Guard Ring**

## Power Supply Layout and Bypass

The TP2401/2402/2402 OPA's power supply pin ($V_{DD}$ for single-supply) should have a local bypass capacitor (i.e., 0.01μF to 0.1μF) within 2mm for good high frequency performance. It can also use a bulk capacitor (i.e., 1μF or larger) within 100mm to provide large, slow currents. This bulk capacitor can be shared with other analog parts.

Ground layout improves performance by decreasing the amount of stray capacitance and noise at the OPA's inputs and outputs. To decrease stray capacitance, minimize PC board lengths and resistor leads, and place external components as close to the op amps' pins as possible.

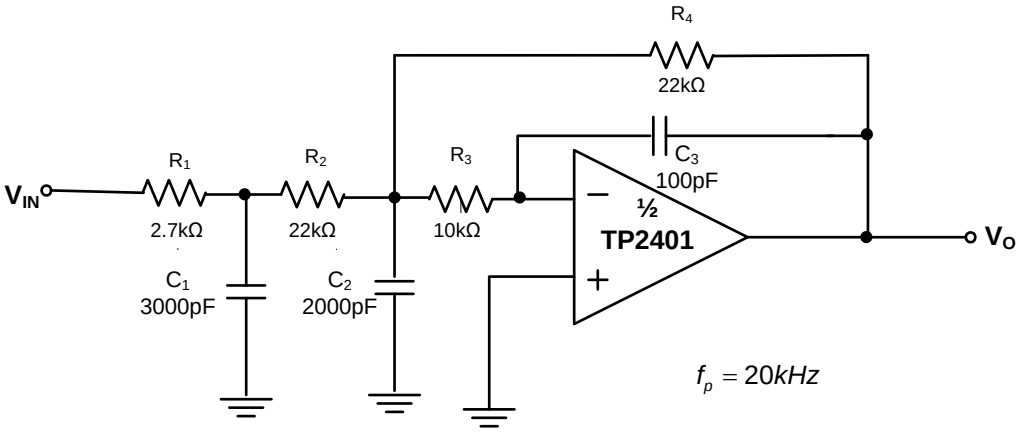
## Proper Board Layout

To ensure optimum performance at the PCB level, care must be taken in the design of the board layout. To avoid leakage currents, the surface of the board should be kept clean and free of moisture. Coating the surface creates a barrier to moisture accumulation and helps reduce parasitic resistance on the board.

Keeping supply traces short and properly bypassing the power supplies minimizes power supply disturbances due to output current variation, such as when driving an ac signal into a heavy load. Bypass capacitors should be connected as closely as possible to the device supply pins. Stray capacitances are a concern at the outputs and the inputs of the amplifier. It is recommended that signal traces be kept at least 5mm from supply lines to minimize coupling.

A variation in temperature across the PCB can cause a mismatch in the Seebeck voltages at solder joints and other points where dissimilar metals are in contact, resulting in thermal voltage errors. To minimize these thermocouple effects, orient resistors so heat sources warm both ends equally. Input signal paths should contain matching numbers and types of components, where possible to match the number and type of thermocouple junctions. For example, dummy components such as zero value resistors can be used to match real resistors in the opposite input path. Matching components should be located in close proximity and should be oriented in the same manner. Ensure leads are of equal length so that thermal conduction is in equilibrium. Keep heat sources on the PCB as far away from amplifier input circuitry as is practical.

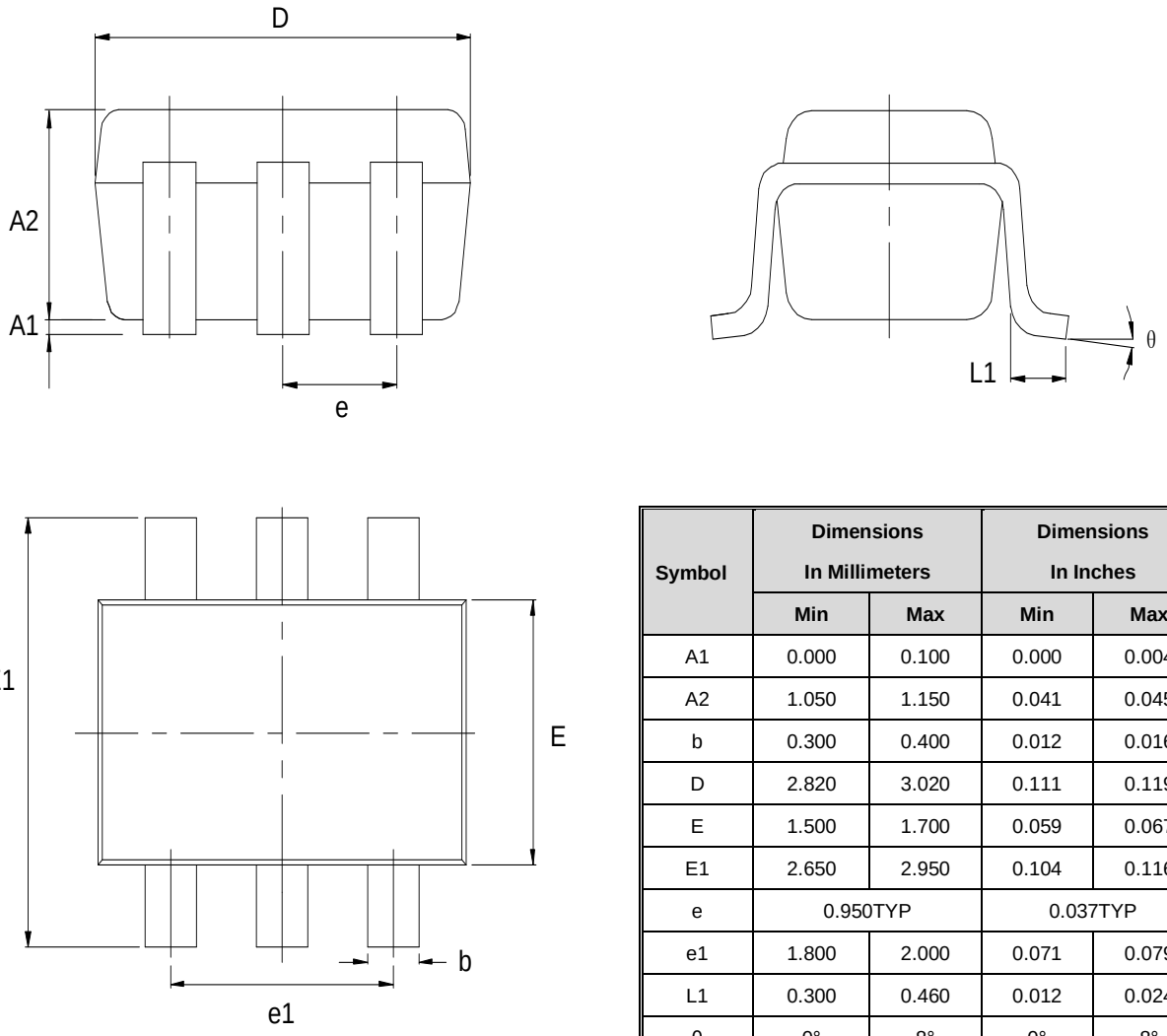
The use of a ground plane is highly recommended. A ground plane reduces EMI noise and also helps to maintain a constant temperature across the circuit board.




**Three-Pole Low-Pass Filter**

## Package Outline Dimensions

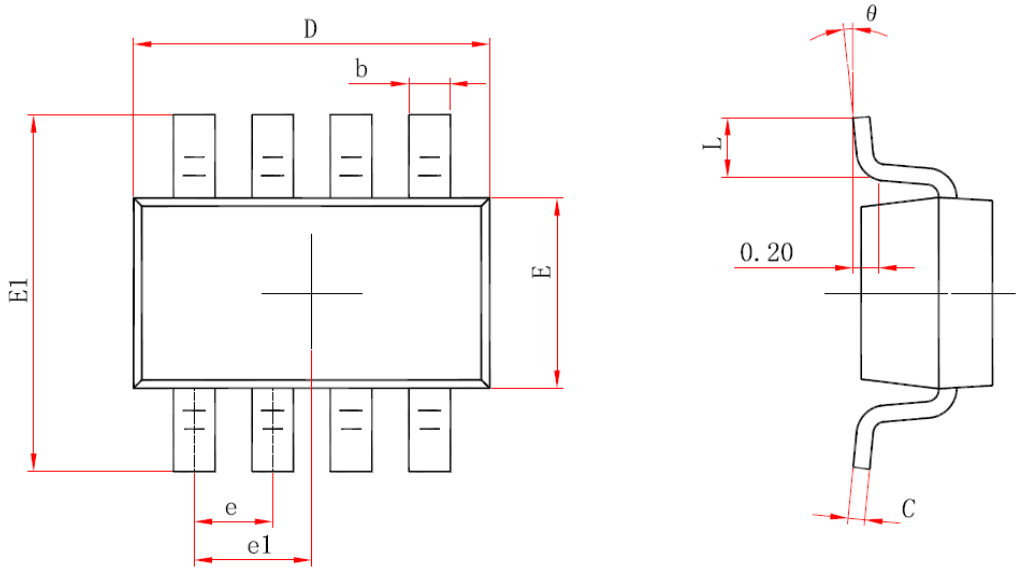
SOT23-5

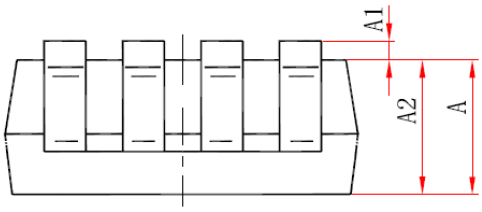



| Symbol | Dimensions In Millimeters | | Dimensions In Inches | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| A1 | 0.000 | 0.100 | 0.000 | 0.004 |
| A2 | 1.050 | 1.150 | 0.041 | 0.045 |
| b | 0.300 | 0.400 | 0.012 | 0.016 |
| D | 2.820 | 3.020 | 0.111 | 0.119 |
| E | 1.500 | 1.700 | 0.059 | 0.067 |
| E1 | 2.650 | 2.950 | 0.104 | 0.116 |
| e | 0.950TYP | | 0.037TYP | |
| e1 | 1.800 | 2.000 | 0.071 | 0.079 |
| L1 | 0.300 | 0.460 | 0.012 | 0.024 |
| θ | 0° | 8° | 0° | 8° |

## Package Outline Dimensions

SOT-23-8

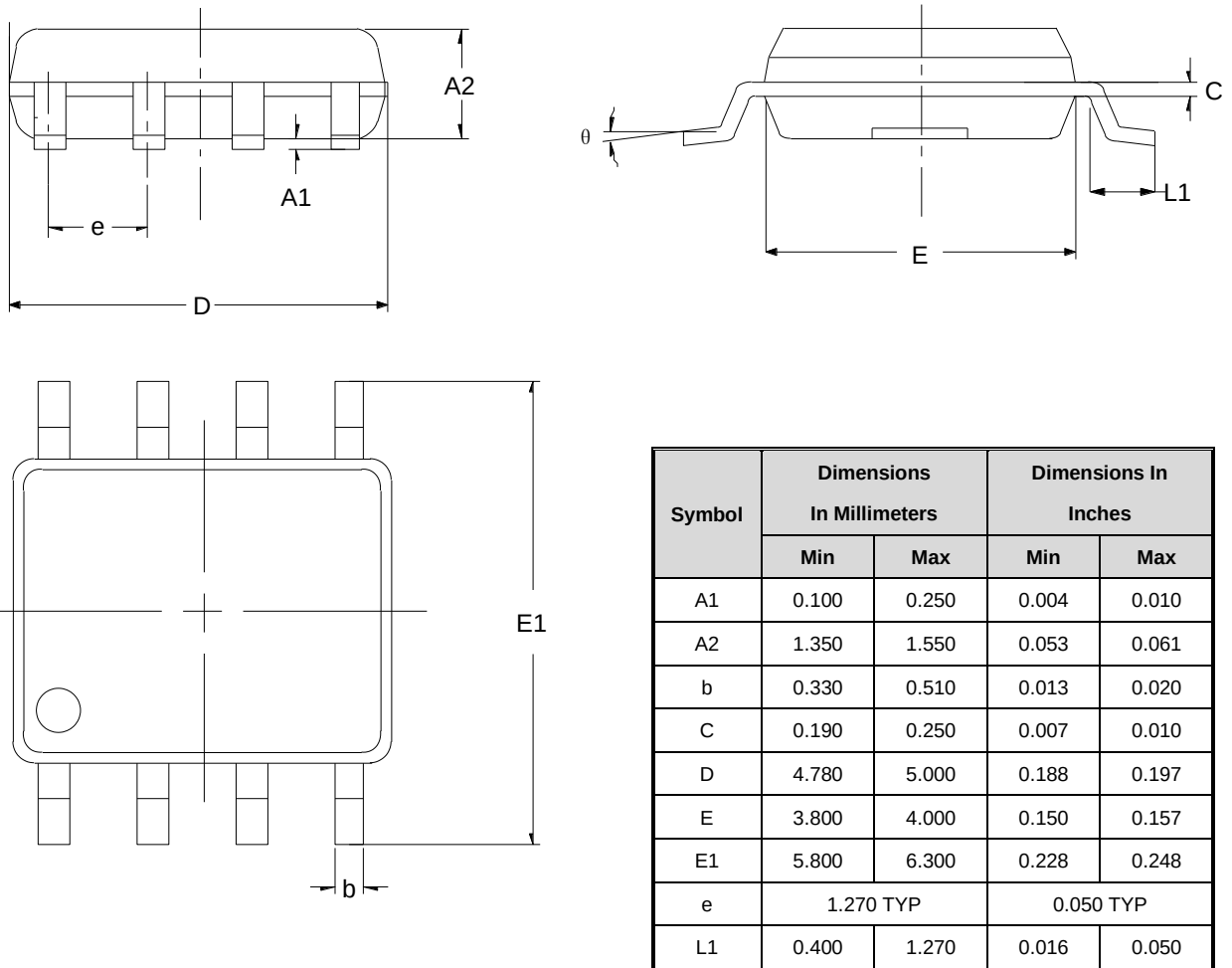



| Symbol | Dimensions In Millimeters | | Dimensions In Inches | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| A | 1.050 | 1.250 | 0.041 | 0.049 |
| A1 | 0.000 | 0.100 | 0.000 | 0.004 |
| A2 | 1.050 | 1.150 | 0.041 | 0.045 |
| b | 0.300 | 0.500 | 0.012 | 0.020 |
| c | 0.100 | 0.200 | 0.004 | 0.008 |
| D | 2.820 | 3.020 | 0.111 | 0.119 |
| E | 1.500 | 1.700 | 0.059 | 0.067 |
| e | 0.65（BSC） | | 0.026(BSC) | |
| e1 | 0.975（BSC） | | 0.038(BSC) | |
| L | 0.300 | 0.600 | 0.012 | 0.024 |
| θ | 0° | 8° | 0° | 8° |

## Package Outline Dimensions

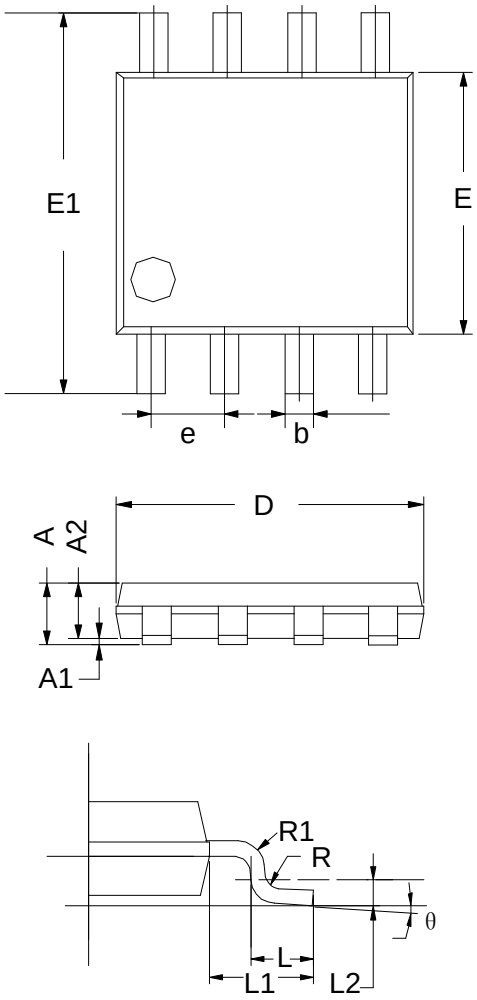
SO-8 (SOIC-8)




| Symbol | Dimensions In Millimeters | | Dimensions In Inches | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| A1 | 0.100 | 0.250 | 0.004 | 0.010 |
| A2 | 1.350 | 1.550 | 0.053 | 0.061 |
| b | 0.330 | 0.510 | 0.013 | 0.020 |
| C | 0.190 | 0.250 | 0.007 | 0.010 |
| D | 4.780 | 5.000 | 0.188 | 0.197 |
| E | 3.800 | 4.000 | 0.150 | 0.157 |
| E1 | 5.800 | 6.300 | 0.228 | 0.248 |
| e | 1.270 TYP | | 0.050 TYP | |
| L1 | 0.400 | 1.270 | 0.016 | 0.050 |
| θ | 0° | 8° | 0° | 8° |

## Package Outline Dimensions

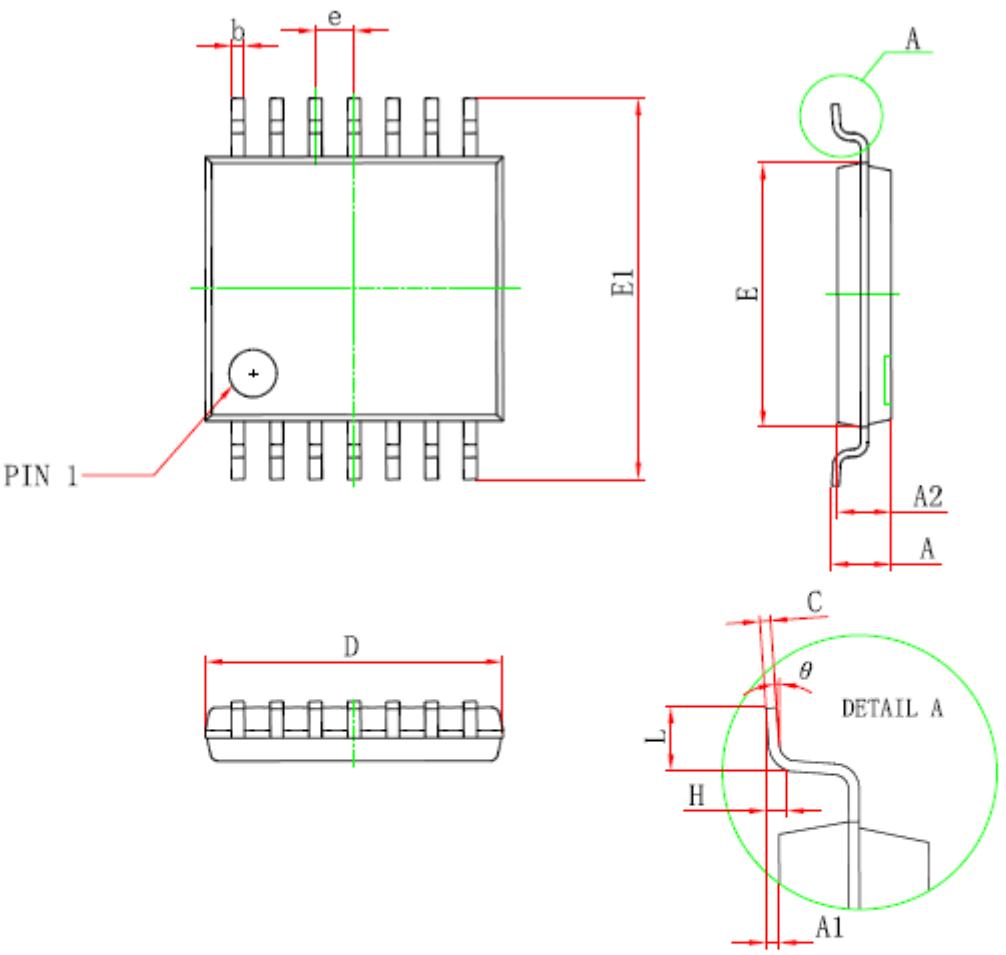
MSOP-8




| Symbol | Dimensions In Millimeters | | Dimensions In Inches | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| A | 0.800 | 1.200 | 0.031 | 0.047 |
| A1 | 0.000 | 0.200 | 0.000 | 0.008 |
| A2 | 0.760 | 0.970 | 0.030 | 0.038 |
| b | 0.30 TYP | | 0.012 TYP | |
| C | 0.15 TYP | | 0.006 TYP | |
| D | 2.900 | 3.100 | 0.114 | 0.122 |
| e | 0.65 TYP | | 0.026 | |
| E | 2.900 | 3.100 | 0.114 | 0.122 |
| E1 | 4.700 | 5.100 | 0.185 | 0.201 |
| L1 | 0.410 | 0.650 | 0.016 | 0.026 |
| θ | 0° | 6° | 0° | 6° |

## Package Outline Dimensions

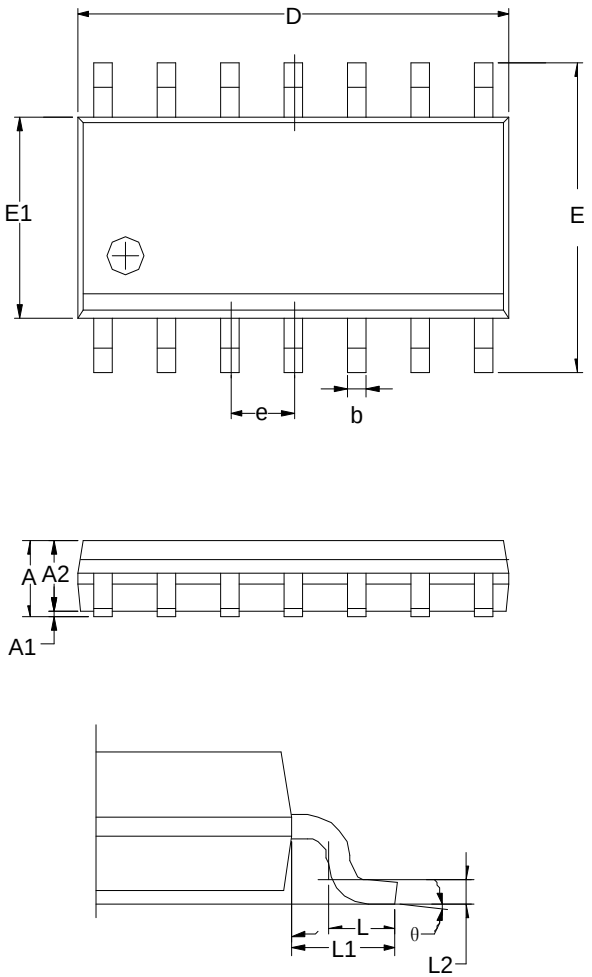
TSSOP-14




| Symbol | Dimensions In Millimeters | | Dimensions In Inches | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| D | 4.900 | 5.100 | 0.193 | 0.201 |
| E | 4.300 | 4.500 | 0.169 | 0.177 |
| b | 0.190 | 0.300 | 0.007 | 0.012 |
| c | 0.090 | 0.200 | 0.004 | 0.008 |
| E1 | 6.250 | 6.550 | 0.246 | 0.258 |
| A | | 1.200 | | 0.047 |
| A2 | 0.800 | 1.000 | 0.031 | 0.039 |
| A1 | 0.050 | 0.150 | 0.002 | 0.006 |
| e | 0.65 (BSC) | | 0.026(BSC) | |
| L | 0.500 | 0.700 | 0.020 | 0.028 |
| H | 0.25(TYP) | | 0.01(TYP) | |
| θ | 1° | 7° | 1° | 7° |

## Package Outline Dimensions

SO-14 (SOIC-14)




| Symbol | Dimensions In Millimeters | | |
|---|---|---|---|
| | MIN | TYP | MAX |
| A | 1.35 | 1.60 | 1.75 |
| A1 | 0.10 | 0.15 | 0.25 |
| A2 | 1.25 | 1.45 | 1.65 |
| b | 0.36 | | 0.49 |
| D | 8.53 | 8.63 | 8.73 |
| E | 5.80 | 6.00 | 6.20 |
| E1 | 3.80 | 3.90 | 4.00 |
| e | 1.27 BSC | | |
| L | 0.45 | 0.60 | 0.80 |
| L1 | 1.04 REF | | |
| L2 | 0.25 BSC | | |
| θ | 0° | | 8° |

## Revision History

| Date | Revision | Notes |
|---|---|---|
| 2022/4/29 | A.3 | Update order information. |

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