

Features

- Supply Current: 950nA Maximum /Amplifier
- Stable 18kHz GBWP with 10mV/μs Slew Rate
- Offset Voltage: 1.5mV Maximum
- Ultra-low V_{OS} TC: 0.5μV/°C
- Ultra-low Input Bias Current: 1fA Typical
- High 120dB Open-Loop Voltage Gain
- Unity Gain Stable for 1,000nF Capacitive Load
- Rail-to-Rail Input/Output Voltage Range
- Outputs Source and Sink 20mA of Load Current
- No Phase Reversal for Overdriven Inputs
- Ultra-low Single-Supply Operation Down to +1.8V
- Shutdown Current: 3nA Typical (TP2121N)
- -40°C to 125°C Operation Range
- Robust 8kV – HBM and 2kV – CDM ESD Rating
- Green, Popular Type Package

Applications

- Handsets and Mobile Accessories
- Current Sensing
- Wireless Remote Sensors, Active RFID Readers
- Environment/Gas/Oxygen Sensors
- Threshold Detectors/Discriminators
- Low Power Filters
- Battery or Solar Powered Devices
- Sensor Network Powered by Energy Scavenging


Description

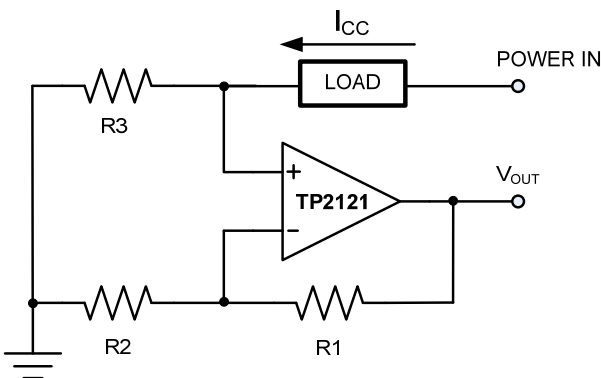
The TP212x are ultra-low power, precision CMOS op-amps featuring a maximum supply current of 950nA per amplifier with an ultra-low typical input bias current of 1fA. Analog trim and calibration routine reduce input offset voltage to below 1.5mV, and the precision temperature compensation technique makes offset voltage temperature drift at 0.5μV/°C, which allowing use of the TP212x in systems with high gain without creating excessively large output offset errors.

The TP212x are unity gain stable with 1,000nF capacitive load with a constant 18kHz GBWP, 10mV/μs slew rate, which make them appropriate for low frequency applications, such as battery current monitoring and sensor conditioning. The TP212x can operate from a single-supply voltage of +1.8V to +6.0V or a dual-supply voltage of ±0.9V to ±3.0V. Beyond the rails input and rail-to-rail output characteristics allow the full power-supply voltage to be used for signal range.

The combined features make the TP212x ideal choices for battery-powered applications because they minimize errors due to power supply voltage variations over the lifetime of the battery and maintain high CMRR even for a rail-to-rail input op-amp. Mobile accessories, wireless remote sensing, backup battery sensors, and single-Li+ or 2-cell NiCd/Alkaline battery powered systems can benefit from the features of the TP212x op-amps.

For applications that require power-down, the TP2121N has a low-power shutdown mode that reduces supply current to 3nA, and forces the output into a high-impedance state.

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$$V_{OUT} = I_{CC} \times R_3 \times \left(\frac{R_1}{R_2} + 1\right)$$

TP2121 in Low Side Battery Current Sensor

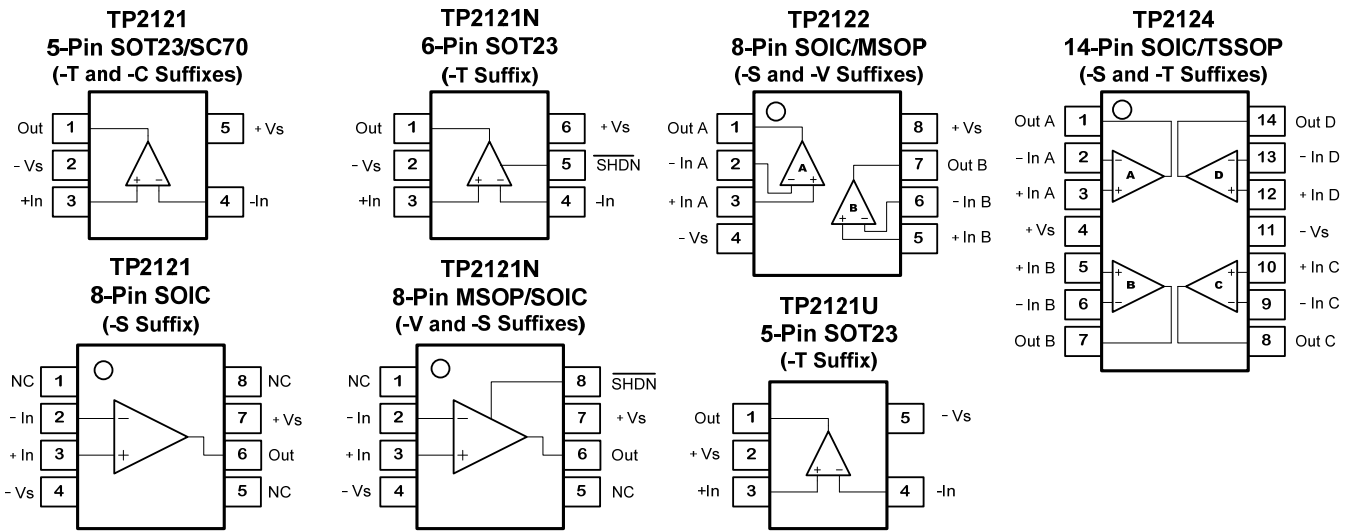
Ultra-low Supply Current Op-amps:

| Supply Current | 0.3 μA | 0.6 μA | 4 μA |
|----------------|---------|---------|---------|
| GBWP | 10 kHz | 18 kHz | 150 kHz |
| Single | TP2111 | TP2121 | TP1511 |
| With Shut-down | TP2111N | TP2121N | TP1511N |
| Dual | TP2112 | TP2122 | TP1512 |
| Quad | TP2114 | TP2124 | TP1514 |

TP2121/TP2121N/TP2122/TP2124

1.8V, 600nA Nanopower, Rail-to-Rail Input/Output Op-amps

Pin Configuration (Top View)



Order Information

| Model Name | Order Number | Package | Transport Media, Quantity | Marking Information |
|------------|--------------|--------------|---------------------------|----------------------|
| TP2121 | TP2121-TR | 5-Pin SOT23 | Tape and Reel, 3,000 | B2TYW ⁽¹⁾ |
| | TP2121-CR | 5-Pin SC70 | Tape and Reel, 3,000 | B2CYW ⁽¹⁾ |
| | TP2121-SR | 8-Pin SOIC | Tape and Reel, 4,000 | 2121S |
| TP2121U | TP2121U-TR | 5-Pin SOT23 | Tape and Reel, 3,000 | B2UYW ⁽¹⁾ |
| TP2121N | TP2121N-TR | 6-Pin SOT23 | Tape and Reel, 3,000 | B2NYW ⁽¹⁾ |
| | TP2121N-VR | 8-Pin MSOP | Tape and Reel, 3,000 | 2121N |
| | TP2121N-SR | 8-Pin SOIC | Tape and Reel, 4,000 | 2121NS |
| TP2122 | TP2122-SR | 8-Pin SOIC | Tape and Reel, 4,000 | B22S |
| | TP2122-VR | 8-Pin MSOP | Tape and Reel, 3,000 | B22V |
| TP2124 | TP2124-SR | 14-Pin SOIC | Tape and Reel, 2,500 | B24S |
| | TP2124-TR | 14-Pin TSSOP | Tape and Reel, 3,000 | B24T |

Note (1): 'YW' is date coding scheme. 'Y' stands for calendar year, and 'W' stands for single workweek coding scheme.

Absolute Maximum Ratings ^{Note 1}

Supply Voltage: $V^+ - V^-$ 6.0V
 Input Voltage $V^- - 0.3$ to $V^+ + 0.3$
 Input Current: +IN, -IN, SHDN ^{Note 2} ± 10 mA
 SHDN Pin Voltage V^- to V^+
 Output Current: OUT ± 20 mA

Output Short-Circuit Duration ^{Note 3} Indefinite
 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 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 3: 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 | MIL-STD-883H Method 3015.8 | 8 | kV |
| CDM | Charged Device Model ESD | JEDEC-EIA/JESD22-C101E | 2 | kV |

TP2121/TP2121N/TP2122/TP2124

1.8V, 600nA Nanopower, Rail-to-Rail Input/Output Op-amps

5V Electrical Characteristics

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 27^\circ\text{C}$. $V_{\text{SUPPLY}} = 5\text{V}$, $V_{\text{CM}} = V_{\text{OUT}} = V_{\text{SUPPLY}}/2$, $R_L = 100\text{k}\Omega$, $C_L = 60\text{pF}$, V_{SHDN} is unconnected.

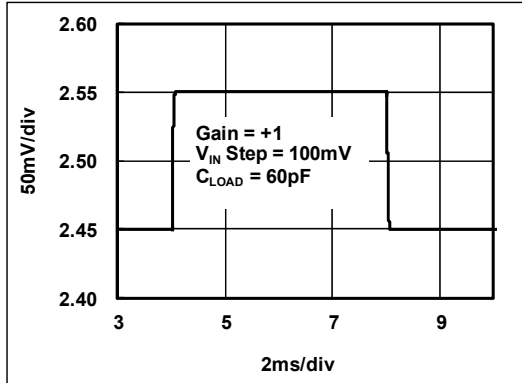
| SYMBOL | PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS | |
|--------------------------------|--|--|---------------|-----------|-------------|------------------------------|--|
| V_{OS} | Input Offset Voltage | $V_{\text{CM}} = V_{\text{DD}}/2$ and $V_{\text{CM}} = \text{GND}$ | ● -1.5 | ± 0.1 | +1.5 | mV | |
| $V_{\text{OS TC}}$ | Input Offset Voltage Drift | | | 0.5 | | $\mu\text{V}/^\circ\text{C}$ | |
| I_{B} | Input Bias Current | $T_A = 27^\circ\text{C}$ | | 1 | | fA | |
| | | $T_A = 85^\circ\text{C}$ | | 700 | | fA | |
| | | $T_A = 125^\circ\text{C}$ | | 45 | | pA | |
| I_{OS} | Input Offset Current | | | 1 | | fA | |
| V_{n} | Input Voltage Noise | $f = 0.1\text{Hz}$ to 10Hz | | 6.5 | | $\mu\text{V}_{\text{P-P}}$ | |
| e_{n} | Input Voltage Noise Density | $f = 1\text{kHz}$ | | 170 | | $\text{nV}/\sqrt{\text{Hz}}$ | |
| R_{IN} | Input Resistance | | | > 1 | | T Ω | |
| C_{IN} | Input Capacitance | Differential | | 2.9 | | pF | |
| | | Common Mode | | 5 | | | |
| CMRR | Common Mode Rejection Ratio | $V_{\text{CM}} = 0.1\text{V}$ to 4.9V | ● 80 | 130 | | dB | |
| V_{CM} | Common-mode Input Voltage Range | | ● $V^- - 0.3$ | | $V^+ + 0.3$ | V | |
| PSRR | Power Supply Rejection Ratio | | ● 60 | 92 | | dB | |
| A_{VOL} | Open-Loop Large Signal Gain | $V_{\text{OUT}} = 2.5\text{V}$, $R_{\text{LOAD}} = 100\text{k}\Omega$ | ● 80 | 120 | | dB | |
| | | $V_{\text{OUT}} = 0.1\text{V}$ to 4.9V , $R_{\text{LOAD}} = 100\text{k}\Omega$ | ● 80 | 120 | | dB | |
| $V_{\text{OL}}, V_{\text{OH}}$ | Output Swing from Supply Rail | $R_{\text{LOAD}} = 100\text{k}\Omega$ | | 5 | | mV | |
| R_{OUT} | Closed-Loop Output Impedance | $G = 1$, $f = 1\text{kHz}$, $I_{\text{OUT}} = 0$ | | 0.4 | | Ω | |
| R_{O} | Open-Loop Output Impedance | $f = 1\text{kHz}$, $I_{\text{OUT}} = 0$ | | 2.6 | | Ω | |
| I_{SC} | Output Short-Circuit Current | Sink or source current | | 20 | | mA | |
| V_{DD} | Supply Voltage | | 1.8 | | 6.0 | V | |
| I_{Q} | Quiescent Current per Amplifier | | ● | 600 | 950 | nA | |
| PM | Phase Margin | $R_{\text{LOAD}} = 100\text{k}\Omega$, $C_{\text{LOAD}} = 60\text{pF}$ | | 61 | | $^\circ$ | |
| GM | Gain Margin | $R_{\text{LOAD}} = 100\text{k}\Omega$, $C_{\text{LOAD}} = 60\text{pF}$ | | -10 | | dB | |
| GBWP | Gain-Bandwidth Product | $f = 1\text{kHz}$ | | 18 | | kHz | |
| t_{s} | Settling Time, 1.5V to 3.5V, Unity Gain | 0.1% | | 0.25 | | ms | |
| | | 0.01% | | 0.253 | | | |
| | | Settling Time, 2.45V to 2.55V, Unity Gain | 0.1% | | 0.035 | | |
| | | 0.01% | | 0.038 | | | |
| SR | Slew Rate | $A_{\text{V}} = 1$, $V_{\text{OUT}} = 1.5\text{V}$ to 3.5V , $C_{\text{LOAD}} = 60\text{pF}$, $R_{\text{LOAD}} = 100\text{k}\Omega$ | | 10 | | $\text{mV}/\mu\text{s}$ | |
| FPBW | Full Power Bandwidth ^{Note 2} | $2V_{\text{P-P}}$ | | 600 | | Hz | |
| $I_{\text{Q(off)}}$ | Supply Current in Shutdown ^{Note 1} | | | 3 | | nA | |
| I_{SHDN} | Shutdown Pin Current ^{Note 1} | $V_{\text{SHDN}} = 0.5\text{V}$ | | -10 | | pA | |
| | | $V_{\text{SHDN}} = 1.5\text{V}$ | | -10 | | | |
| I_{LEAK} | Output Leakage Current in Shutdown ^{Note 1} | $V_{\text{SHDN}} = 0\text{V}$, $V_{\text{OUT}} = 0\text{V}$ | | -3.6 | | pA | |
| | | $V_{\text{SHDN}} = 0\text{V}$, $V_{\text{OUT}} = 5\text{V}$ | | 3.6 | | | |
| V_{IL} | SHDN Input Low Voltage ^{Note 1} | Disable | ● | | 0.5 | V | |
| V_{IH} | SHDN Input High Voltage ^{Note 1} | Enable | ● | 1.0 | | V | |

Note 1: Specifications apply to the TP2121N with shutdown.

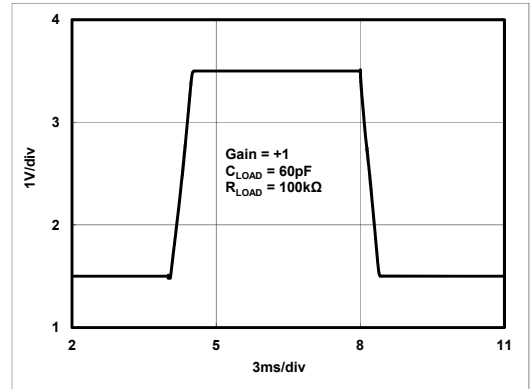
Note 2: Full power bandwidth is calculated from the slew rate $\text{FPBW} = \text{SR}/\pi \cdot V_{\text{P-P}}$.

Typical Performance Characteristics

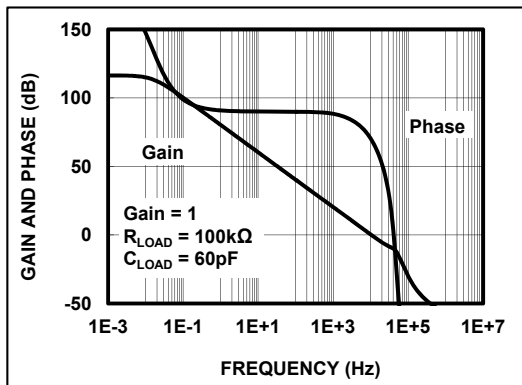
Small-Signal Step Response, 100mV Step



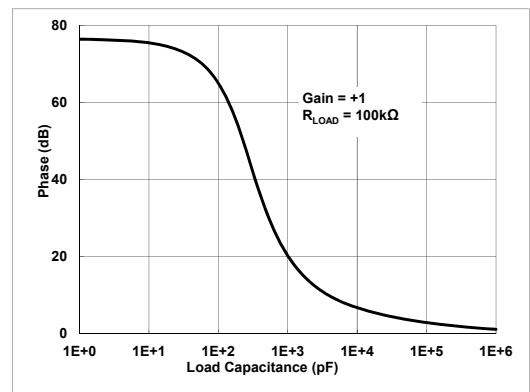
Large-Signal Step Response, 2V Step



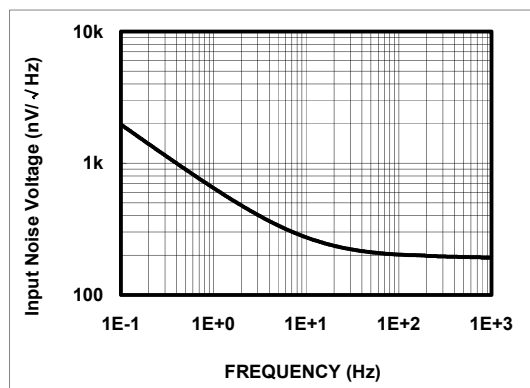
Open-Loop Gain and Phase



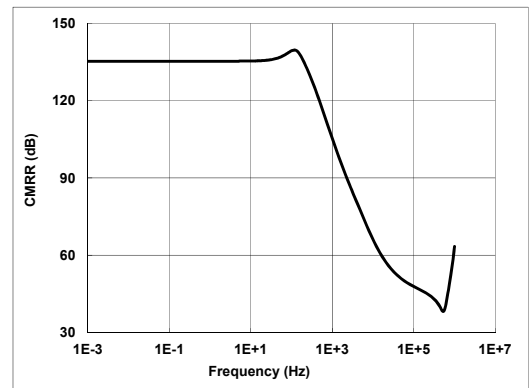
Phase Margin vs. C_{LOAD} (Stable for Any C_{LOAD})



Input Voltage Noise Spectral Density



Common-Mode Rejection Ratio

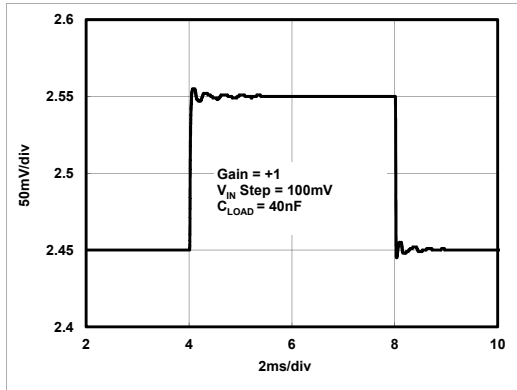


TP2121/TP2121N/TP2122/TP2124

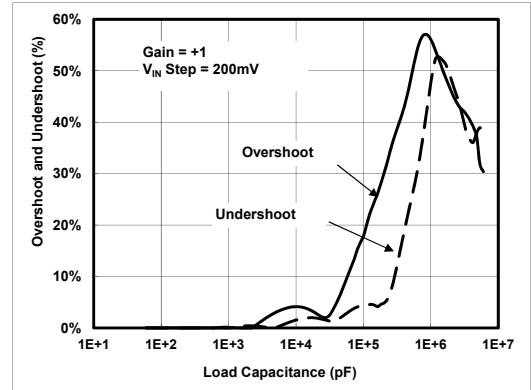
1.8V, 600nA Nanopower, Rail-to-Rail Input/Output Op-amps

Typical Performance Characteristics

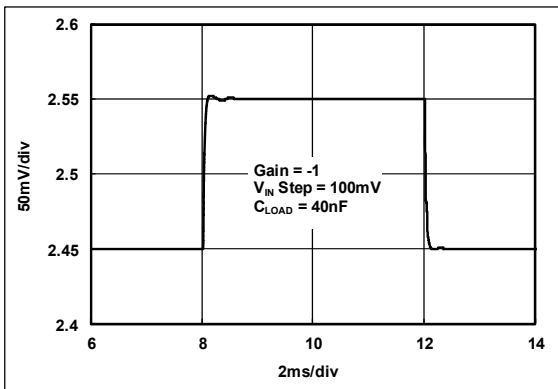
Over-Shoot Voltage, $C_{LOAD} = 40\text{nF}$, Gain = +1, $R_{FB}=100\text{k}\Omega$



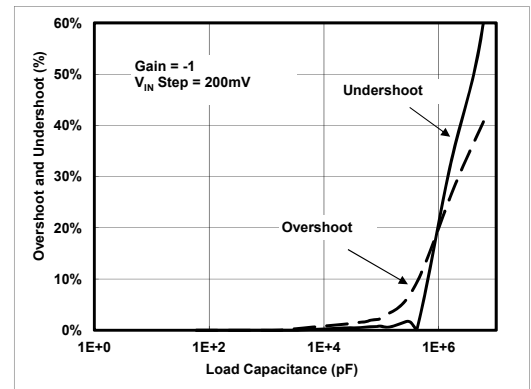
Over-Shoot % vs. C_{LOAD} , Gain = +1, $R_{FB} = 1\text{M}\Omega$



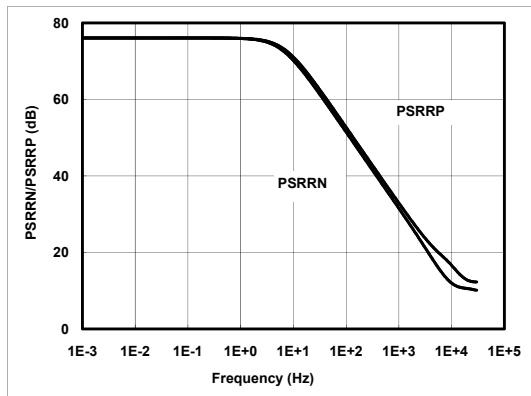
Over-Shoot Voltage, $C_{LOAD}=40\text{nF}$, Gain = -1, $R_{FB}=100\text{k}\Omega$



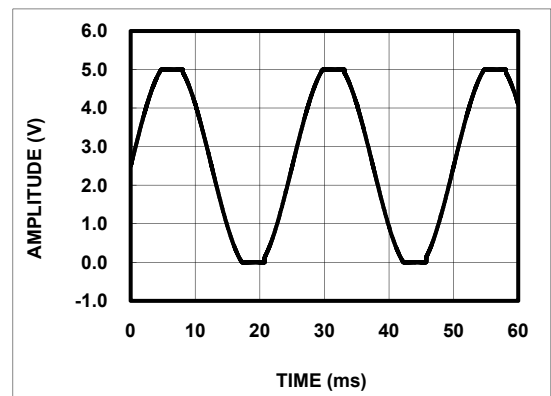
Over-Shoot % vs. C_{LOAD} , Gain = -1, $R_{FB} = 1\text{M}\Omega$



Power-Supply Rejection Ratio

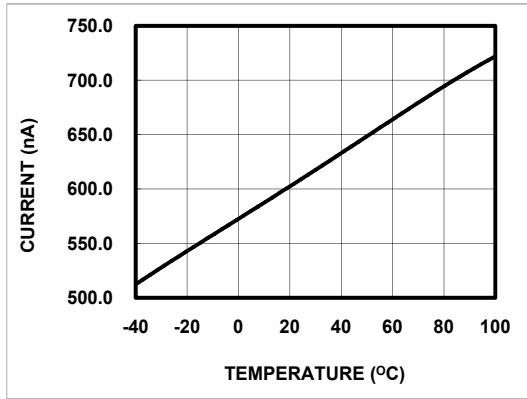


$V_{IN} = -0.2\text{V}$ to 5.7V , No Phase Reversal

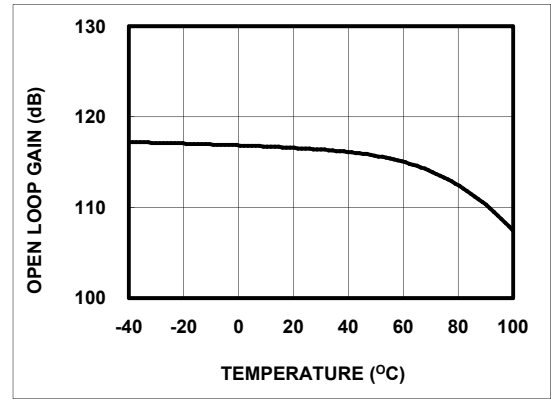


Typical Performance Characteristics

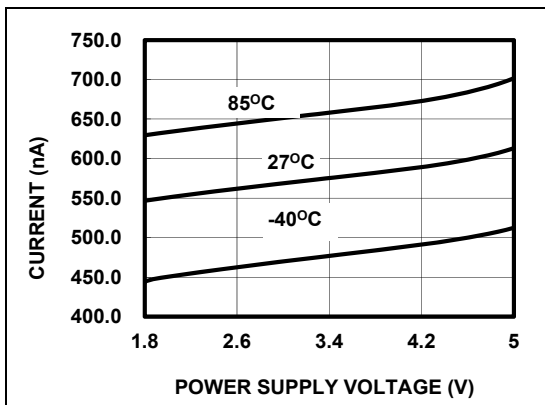
Quiescent Supply Current vs. Temperature



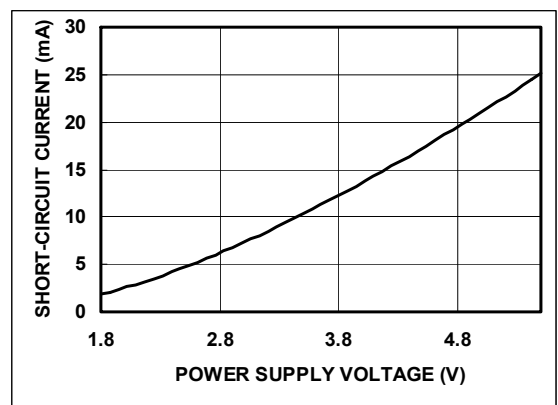
Open-Loop Gain vs. Temperature



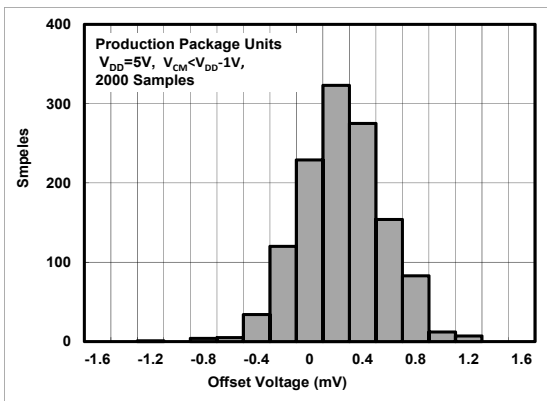
Quiescent Supply Current vs. Supply Voltage



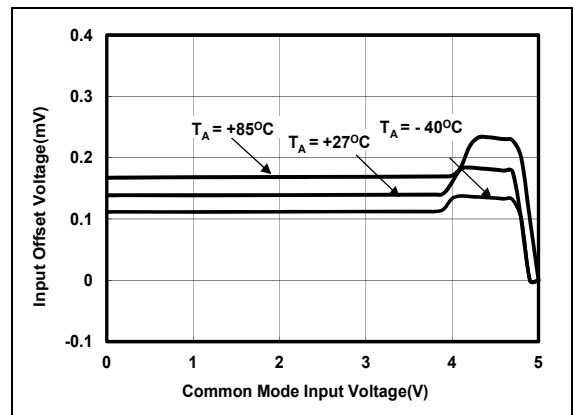
Short-Circuit Current vs. Supply Voltage



Input Offset Voltage Distribution



Input Offset Voltage vs. Common Mode Input Voltage

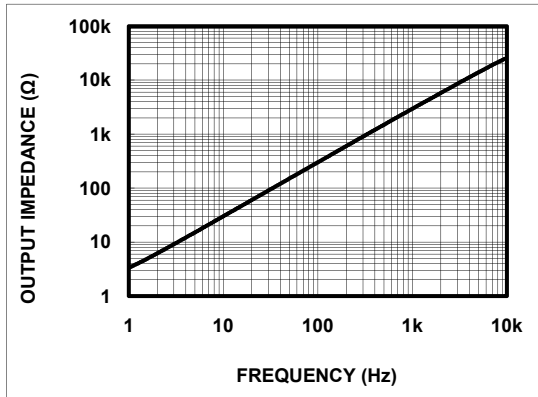


TP2121/TP2121N/TP2122/TP2124

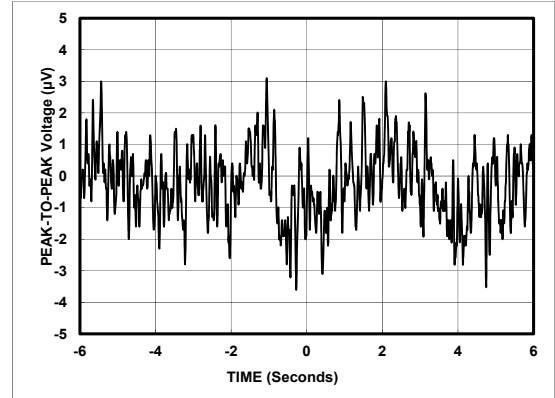
1.8V, 600nA Nanopower, Rail-to-Rail Input/Output Op-amps

Typical Performance Characteristics

Closed-Loop Output Impedance vs. Frequency



0.1Hz to 10Hz Time Domain Output Voltage Noise



Pin Functions

-IN: Inverting Input of the Amplifier. Voltage range of this pin can go from $V^- - 0.3V$ to $V^+ + 0.3V$.

+IN: Non-Inverting Input of Amplifier. This pin has the same voltage range as -IN.

V+ or +Vs: Positive Power Supply. Typically the voltage is from 1.8V to 5.5V. Split supplies are possible as long as the voltage between V+ and V- is between 1.8V 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.

N/C: No Connection.

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 1.8V 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.

SHDN: Active **Low** Shutdown. Shutdown threshold is **1.0V** above negative supply rail. If unconnected, the amplifier is automatically enabled.

OUT: Amplifier Output. The voltage range extends to within milli-volts of each supply rail.

Operation

The TP212x family input signal range extends beyond the negative and positive power supplies. The output can even extend all the way to the negative supply. The input stage is comprised of two CMOS differential amplifiers, a PMOS stage and NMOS stage that are active over different ranges of common mode input

voltage. The Class-AB control buffer and output bias stage uses a proprietary compensation technique to take full advantage of the process technology to drive very high capacitive loads. This is evident from the transient over shoot measurement plots in the Typical Performance Characteristics.

Applications Information

Low Supply Voltage and Low Power Consumption

The TP212x family of operational amplifiers can operate with power supply voltages from 1.8V to 6.0V. Each amplifier draws only 600nA quiescent current. The low supply voltage capability and low supply current are ideal for portable applications demanding HIGH CAPACITIVE LOAD DRIVING CAPABILITY and CONSTANT WIDE BANDWIDTH. The TP212x family is optimized for wide bandwidth low power applications. They have an industry leading high GBWP to power ratio and are unity gain stable for 1,000nF capacitive load. When the load capacitance increases, the increased capacitance at the output pushed the non-dominant pole to lower frequency in the open loop frequency response, lowering the phase and gain margin. Higher gain configurations tend to have better capacitive drive capability than lower gain configurations due to lower closed loop bandwidth and hence higher phase margin.

Low Input Referred Noise

The TP212x family provides a low input referred noise density of 170nV/√Hz at 1kHz. The voltage noise will grow slowly with the frequency in wideband range, and the input voltage noise is typically 6.5μV_{P-P} at the frequency of 0.1Hz to 10Hz.

Low Input Offset Voltage

The TP212x family has a low offset voltage of 1.5mV maximum which is essential for precision applications. The offset voltage is trimmed with a proprietary trim algorithm to ensure low offset voltage for precision signal processing requirement.

Low Input Bias Current

The TP212x family is a CMOS OPA family and features very low input bias current in pA range. The low input bias current allows the amplifiers to be used in applications with high resistance sources. Care must be taken to minimize PCB Surface Leakage. See below section on “PCB Surface Leakage” for more details.

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 10¹²Ω. A 5V difference would cause 5pA of current to flow, which is greater than the TP212x OPA’s input bias current at +27°C (±1fA, 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.

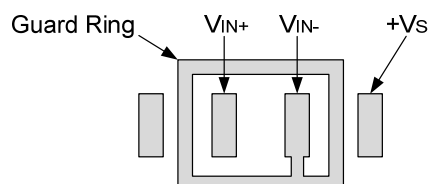


Figure 1

Ground Sensing and Rail to Rail Output

The TP212x family has excellent output drive capability, delivering over 10mA of output drive current. The output stage is a rail-to-rail topology that is capable of swinging to within 5mV of either rail. Since the inputs can go 300mV beyond either rail, the op-amp can easily perform ‘true ground’ sensing.

TP2121/TP2121N/TP2122/TP2124

1.8V, 600nA Nanopower, Rail-to-Rail Input/Output Op-amps

The maximum output current is a function of total supply voltage. As the supply voltage to the amplifier increases, the output current capability also increases. Attention must be paid to keep the junction temperature of the IC below 150°C when the output is in continuous short-circuit. The output of the amplifier has reverse-biased ESD diodes connected to each supply. The output should not be forced more than 0.5V beyond either supply, otherwise current will flow through these diodes.

ESD

The TP212x family has reverse-biased ESD protection diodes on all inputs and output. Input and out pins can not be biased more than 300mV beyond either supply rail.

Shut-down

The single channel OPA versions have SHDN pins that can shut down the amplifier to typical 3nA supply current. The SHDN pin voltage needs to be within 0.5V of V^- for the amplifier to shut down. During shutdown, the output will be in high output resistance state, which is suitable for multiplexer applications. When left floating, the SHDN pin is internally pulled up to the positive supply and the amplifier remains enabled.

Driving Large Capacitive Load

The TP212x family of OPA is designed to drive large capacitive loads. Refer to Typical Performance Characteristics for “Phase Margin vs. Load Capacitance”. As always, larger load capacitance decreases overall phase margin in a feedback system where internal frequency compensation is utilized. As the load capacitance increases, the feedback loop’s phase margin decreases, and the closed-loop bandwidth is reduced. This produces gain peaking in the frequency response, with overshoot and ringing in output step response. The unity-gain buffer ($G = +1V/V$) is the most sensitive to large capacitive loads.

When driving large capacitive loads with the TP212x OPA family (e.g., > 200 pF when $G = +1V/V$), a small series resistor at the output (R_{iso} in Figure 2) improves the feedback loop’s phase margin and stability by making the output load resistive at higher frequencies.

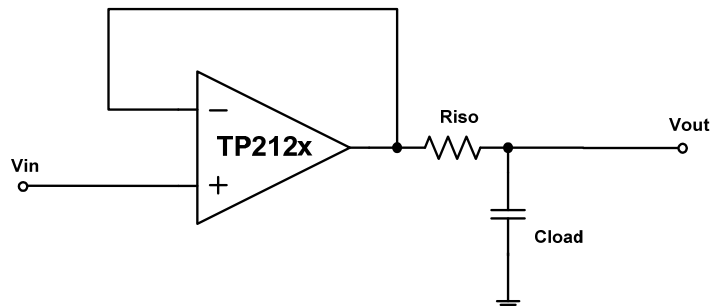


Figure 2

Power Supply Layout and Bypass

The TP212x OPA’s power supply pin (V_{DD} for single-supply) should have a local bypass capacitor (i.e., 0.01 μ F to 0.1 μ F) within 2mm for good high frequency performance. It can also use a bulk capacitor (i.e., 1 μ F 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 PCB 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.

BATTERY CURRENT SENSING

The Common Mode Input voltage Range of TP212x OPA series, which goes 0.3V beyond both supply rails, supports their use in high-side and low-side battery current sensing applications. The low quiescent current (600nA, typical) helps prolong battery life, and the rail-to-rail output supports detection of low currents.

The battery current (I_{DD}) through the 10Ω resistor causes its top terminal to be more negative than the bottom terminal. This keeps the Common Mode Input voltage below V_{DD} , which is within its allowed range. The output of the OPA will also be blow V_{DD} , within its Maximum Output Voltage Swing specification.

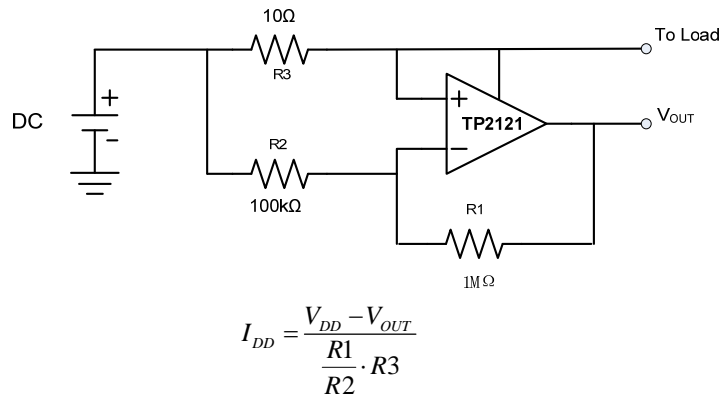


Figure 3

Instrumentation Amplifier

The TP212x OPA series is well suited for conditioning sensor signals in battery-powered applications. Figure 4 shows a two op-amp instrumentation amplifier, using the TP212x OPA.

The circuit works well for applications requiring rejection of Common Mode noise at higher gains. The reference voltage (V_{REF}) is supplied by a low-impedance source. In single voltage supply applications, V_{REF} is typically $V_{DD}/2$.

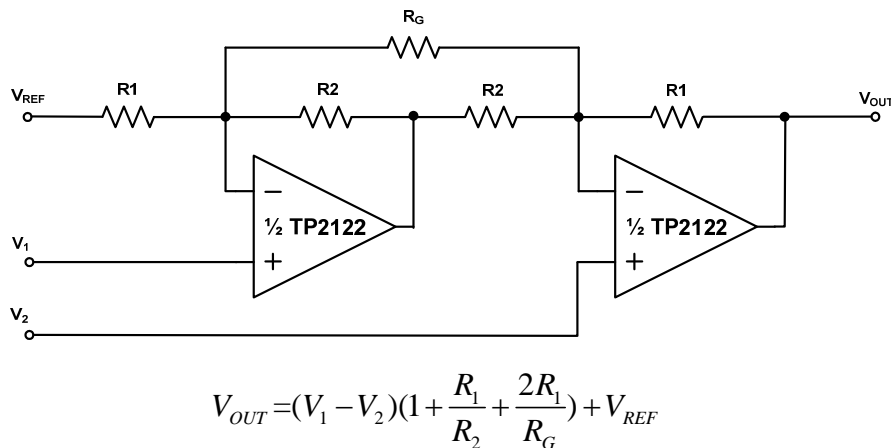


Figure 4

Buffered Chemical Sensor (pH) Probe

The TP212x OPA has input bias current in the pA range. This is ideal in buffering high impedance chemical sensors such as pH probe. As an example, the circuit in Figure 5 eliminates expensive low-leakage cables that that is required to connect pH probe to metering ICs such as ADC, AFE and/or MCU. A TP212x OPA and a lithium battery are housed in the probe assembly. A conventional low-cost coaxial cable can be used to carry OPA's output signal to subsequent ICs for pH reading.

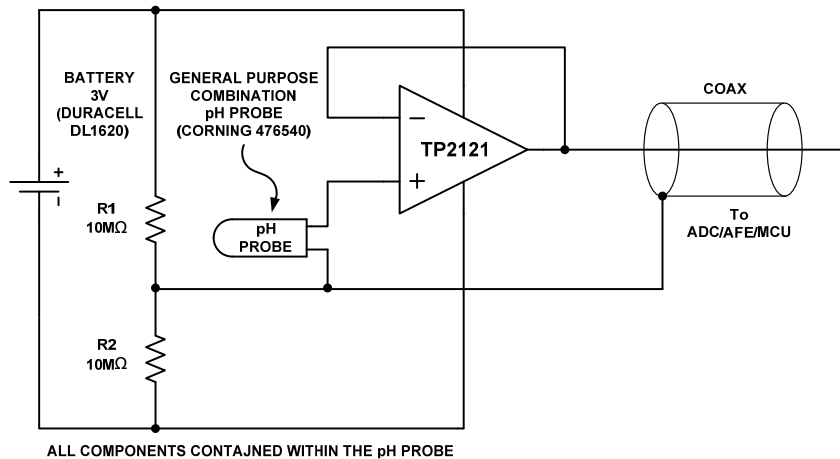


Figure 5: Buffer pH Probe

Portable Gas Sensor Amplifier

Gas sensors are used in many different industrial and medical applications. Gas sensors generate a current that is proportional to the percentage of a particular gas concentration sensed in an air sample. This output current flows through a load resistor and the resultant voltage drop is amplified. Depending on the sensed gas and sensitivity of the sensor, the output current can be in the range of tens of microamperes to a few milli-amperes. Gas sensor datasheets often specify a recommended load resistor value or a range of load resistors from which to choose.

There are two main applications for oxygen sensors – applications which sense oxygen when it is abundantly present (that is, in air or near an oxygen tank) and those which detect traces of oxygen in parts-per-million concentration. In medical applications, oxygen sensors are used when air quality or oxygen delivered to a patient needs to be monitored. In fresh air, the concentration of oxygen is 20.9% and air samples containing less than 18% oxygen are considered dangerous. In industrial applications, oxygen sensors are used to detect the absence of oxygen; for example, vacuum-packaging of food products.

The circuit in Figure 6 illustrates a typical implementation used to amplify the output of an oxygen detector. With the components shown in the figure, the circuit consumes less than 600nA of supply current ensuring that small form-factor single- or button-cell batteries (exhibiting low mAh charge ratings) could last beyond the operating life of the oxygen sensor. The precision specifications of these amplifiers, such as their low offset voltage, low $V_{OS\ TC}$, low input bias current, high CMRR, and high PSRR are other factors which make these amplifiers excellent choices for this application.

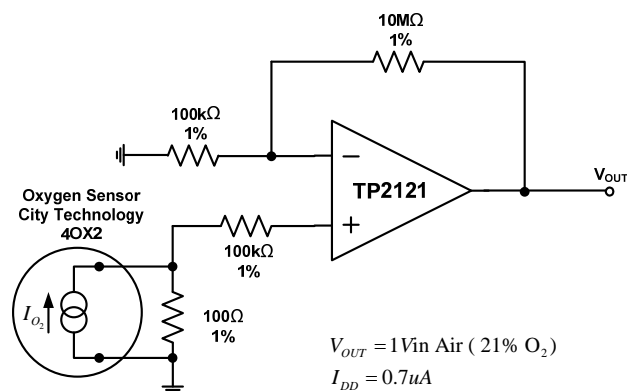
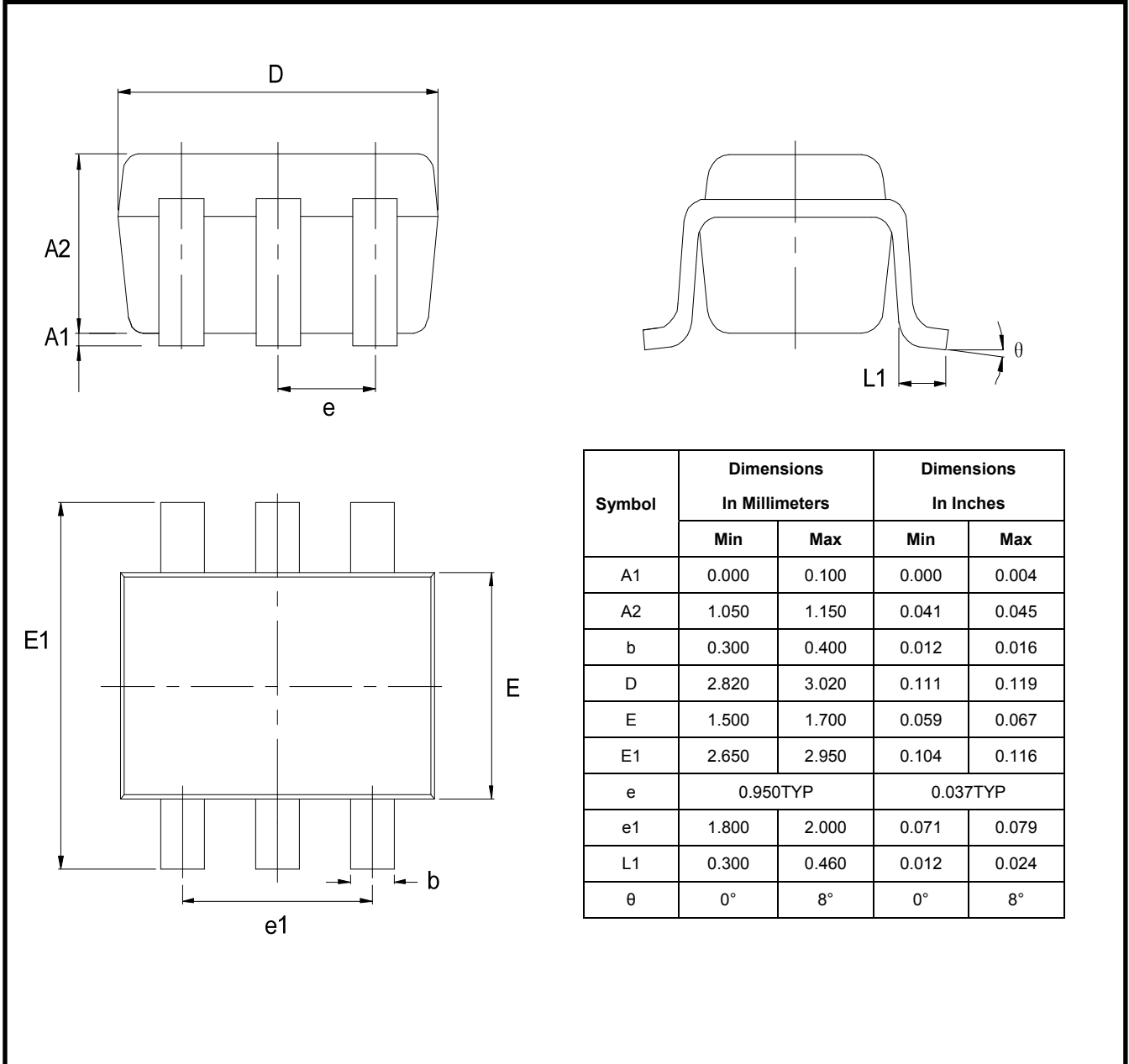


Figure 6

Package Outline Dimensions

SOT23-5 / SOT23-6

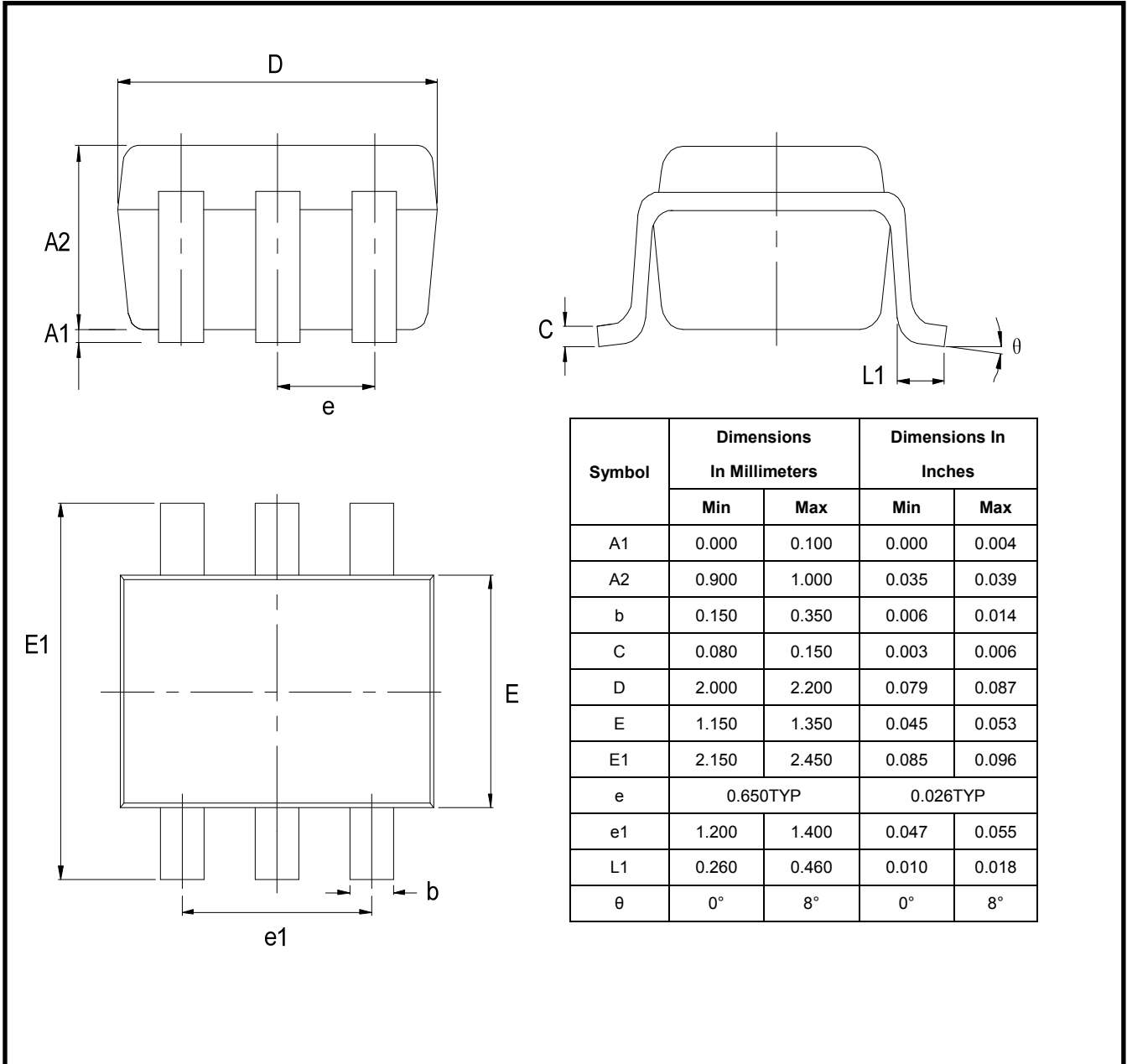


TP2121/TP2121N/TP2122/TP2124

1.8V, 600nA Nanopower, Rail-to-Rail Input/Output Op-amps

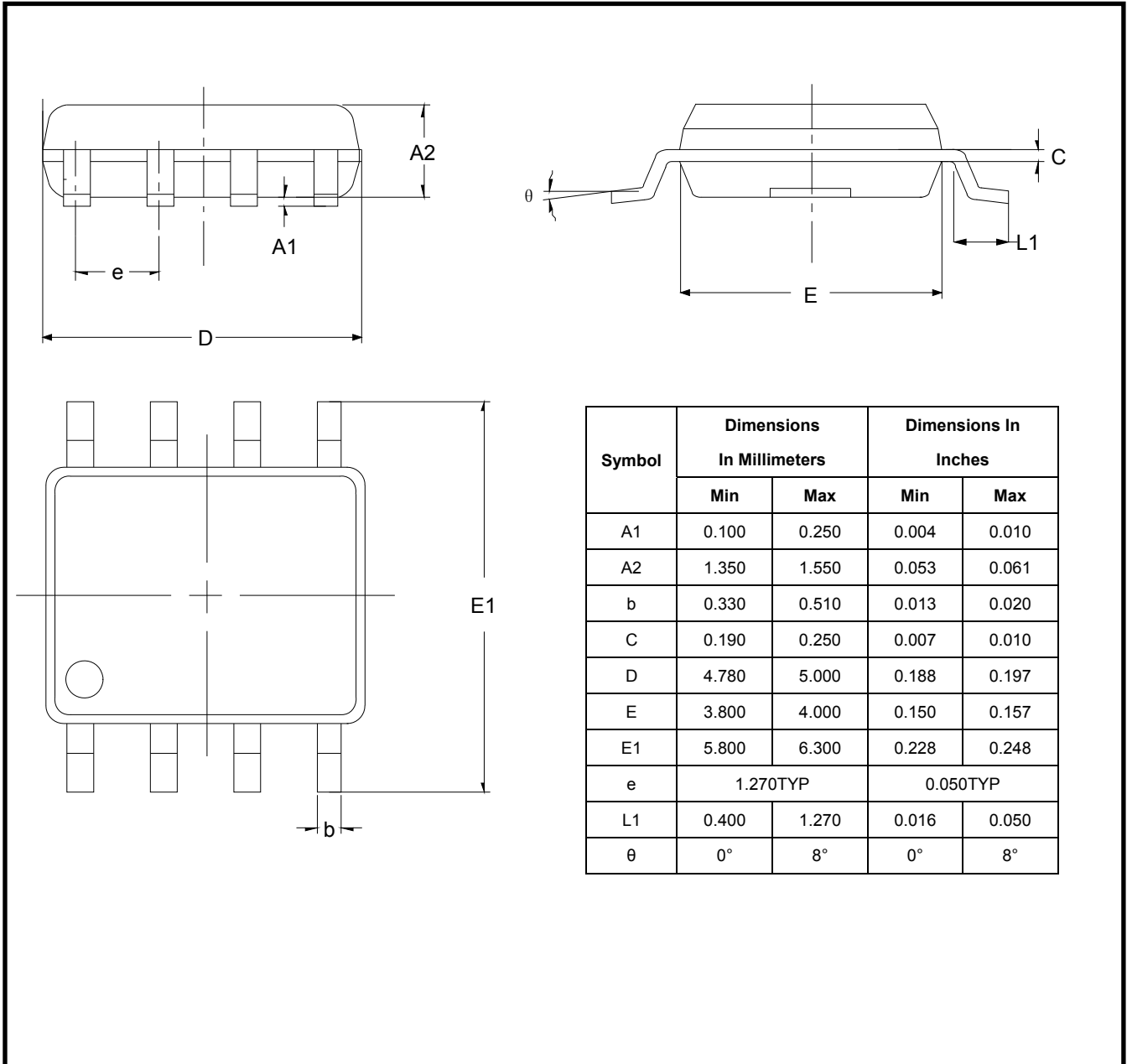
Package Outline Dimensions

SC-70-5 / SC-70-6 (SOT353 / SOT363)



Package Outline Dimensions

SO-8 (SOIC-8)

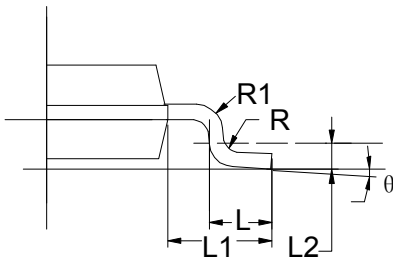
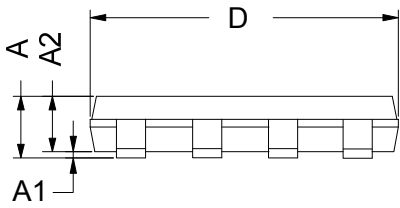
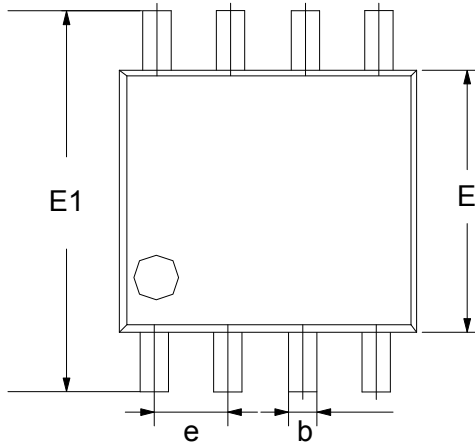


Package Outline Dimensions

TP2121/TP2121N/TP2122/TP2124

1.8V, 600nA Nanopower, Rail-to-Rail Input/Output Op-amps

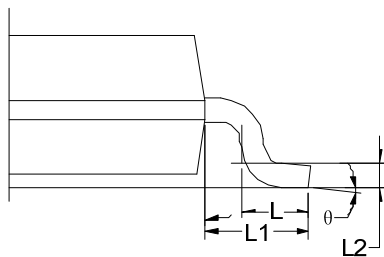
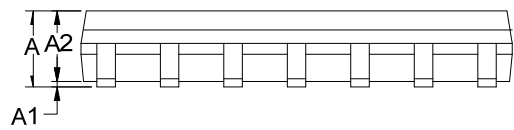
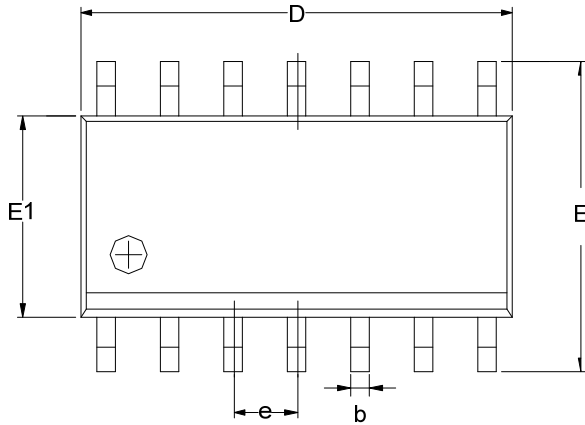
MSOP-8



| 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

SO-14 (SOIC-14)



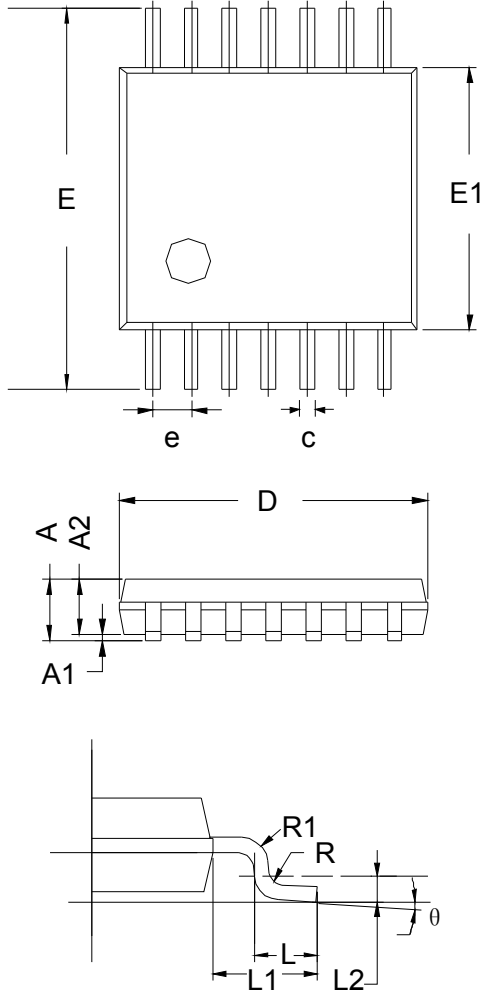
| Symbol | Dimensions In Millimeters | | |
|--------|------------------------------|------|------|
| | MIN | TYP | MAX |
| A | 1.35 | 1.60 | 1.75 |
| A1 | 0.10 | 0.15 | 0.25 |
| A2 | 1.25 | 1.45 | 1.65 |
| b | 0.36 | | 0.49 |
| D | 8.53 | 8.63 | 8.73 |
| E | 5.80 | 6.00 | 6.20 |
| E1 | 3.80 | 3.90 |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

TP2121/TP2121N/TP2122/TP2124

1.8V, 600nA Nanopower, Rail-to-Rail Input/Output Op-amps

Package Outline Dimensions

TSSOP-14



| Symbol | Dimensions In Millimeters | | |
|--------|------------------------------|------|------|
| | MIN | TYP | MAX |
| A | - | - | 1.20 |
| A1 | 0.05 | - | 0.15 |
| A2 | 0.90 | 1.00 | 1.05 |
| b | 0.20 | - | 0.28 |
| c | 0.10 | - | 0.19 |
| D | 4.86 | 4.96 | 5.06 |
| E | 6.20 | 6.40 | 6.60 |
| E1 | 4.30 | 4.40 | 4.50 |
| e | 0.65 BSC | | |
| L | 0.45 | 0.60 | 0.75 |
| L1 | 1.00 REF | | |
| L2 | 0.25 BSC | | |
| R | 0.09 | - | - |
| θ | 0° | - | 8° |