

Features

- Ultra-low Supply Current: 300nA Typical / 500nA Maximum per Amplifier
- Stable 10 kHz GBWP with 6 mV/μs Slew Rate
- Offset Voltage: 1.5 mV Maximum
- Ultra-low V_{OS} TC: 0.4 μV/°C
- Ultra-low Input Bias Current: 0.1 fA Typical
- Unity Gain Stable for 1,000 nF Capacitive Load
- High 120 dB Open-Loop Voltage Gain
- Ground-Sensing Input Common-Mode Range
- Outputs Swing Rail-to-Rail
- Outputs Source and Sink 20 mA of Load Current
- No Phase Reversal for Overdriven Inputs
- Ultra-low Single-Supply Operation Down to +1.8V
- Shutdown Current: 3 nA Typical (TP2111N)
- -40°C to 125°C Operation Range
- Robust 8 kV – HBM and 2 kV – CDM ESD Rating
- Green, Popular Type Package

Applications

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

Description

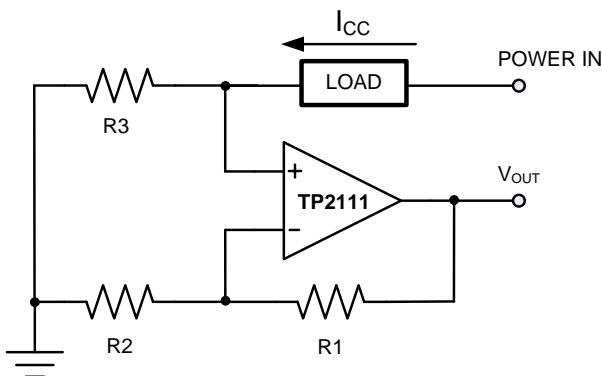
The TP211x are ultra-low power, precision CMOS op-amps that provide a constant 10kHz bandwidth and 10mV/μs slew rate with only 300nA quiescent current per amplifier. The ground-sensing input common-mode range, guaranteed 1.5mV V_{OS} and ultra-low 0.4μV/°C V_{OS} TC enables accurate and stable measurement for both high side and low side current sensing.

The TP211x have carefully designed CMOS input stage that outperforms competitors with typically 0.1fA I_B. This ultra-low input current significantly reduces I_B and I_{OS} errors introduced in giga-Ω resistance, high impedance photodiode, and charge sense situations. The TP211x are unity gain stable with 1,000nF capacitive load. They can operate from a single -supply voltage of +1.8V to +6.0V or a dual-supply voltage of ±0.9V to ±3.0V, and features ground-sensing inputs and rail-to-rail output.

The combined features make the TP211x ideally suited for a variety of 2-cell NiCd/Alkaline battery or single-Li+ battery powered portable applications. Potential applications include low frequency signal conditioning, mobile accessories, wireless remote sensing, vibration monitors, ECGs, pulse monitors, glucose meters, smoke and fire detectors, and backup battery sensors.

For applications that require power-down, the TP2111N has a low-power shutdown mode that reduces supply current to 3nA typically, and forces the output into a high-impedance state.

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

TP2111 in Low Side Battery Current Sensor

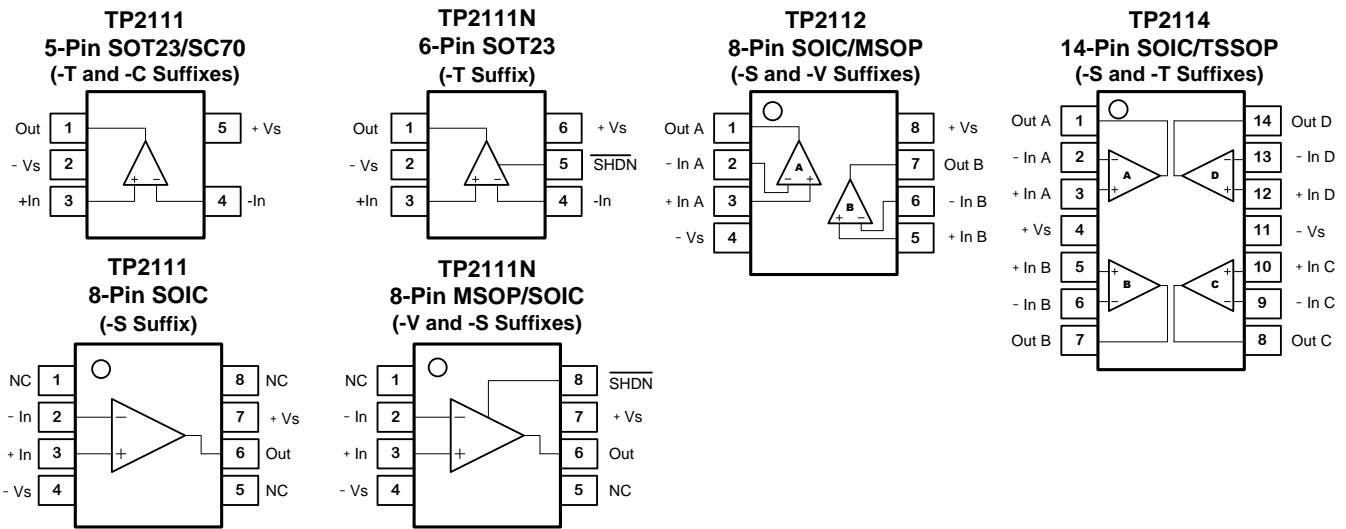
Ultra-low Supply Current Op-amps:

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

TP2111/TP2111N/TP2112/TP2114

Nanopower 300nA, 1.8V, Rail-to-Rail Input/Output Op-amps

Pin Configuration (Top View)



Order Information

Model Name	Order Number	Package	Transport Media, Quantity	Marking Information
TP2111	TP2111-TR	5-Pin SOT23	Tape and Reel, 3,000	B1TYW ⁽¹⁾
	TP2111-CR	5-Pin SC70	Tape and Reel, 3,000	B1CYW ⁽¹⁾
	TP2111-SR	8-Pin SOIC	Tape and Reel, 4,000	2111S
TP2111N	TP2111N-TR	6-Pin SOT23	Tape and Reel, 3,000	B1NYW ⁽¹⁾
	TP2111N-VR	8-Pin MSOP	Tape and Reel, 3,000	2111N
	TP2111N-SR	8-Pin SOIC	Tape and Reel, 4,000	2111NS
TP2112	TP2112-SR	8-Pin SOIC	Tape and Reel, 4,000	B12S
	TP2112-VR	8-Pin MSOP	Tape and Reel, 3,000	B12V
TP2114	TP2114-SR	14-Pin SOIC	Tape and Reel, 2,500	B14S
	TP2114-TR	14-Pin TSSOP	Tape and Reel, 3,000	B14T

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

TP2111/TP2111N/TP2112/TP2114

Nanopower 300nA, 1.8V, 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.

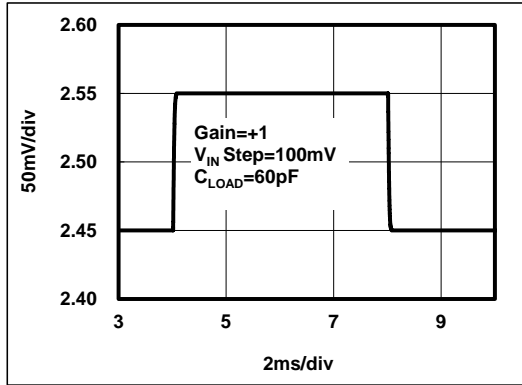
SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	$V_{\text{CM}} = V_{\text{DD}}/2$	● -1.5	± 0.1	+1.5	mV
$V_{\text{OS TC}}$	Input Offset Voltage Drift			0.4		$\mu\text{V}/^\circ\text{C}$
I_{B}	Input Bias Current	$T_A = 27^\circ\text{C}$		0.1		fA
		$T_A = 85^\circ\text{C}$		78		fA
		$T_A = 125^\circ\text{C}$		4.5		pA
I_{OS}	Input Offset Current			0.1		fA
V_{n}	Input Voltage Noise	$f = 0.1\text{Hz to } 10\text{Hz}$		10		$\mu\text{V}_{\text{P-P}}$
e_{n}	Input Voltage Noise Density	$f = 1\text{kHz}$		265		$\text{nV}/\sqrt{\text{Hz}}$
R_{IN}	Input Resistance			> 100		G Ω
C_{IN}	Input Capacitance	Differential		2.9		pF
		Common Mode		5		
CMRR	Common Mode Rejection Ratio	$V_{\text{CM}} = 0.1\text{V to } 4.9\text{V}$	● 80	130		dB
V_{CM}	Common-mode Input Voltage Range		● $V^- - 0.3$		$V^+ + 0.3$	V
PSRR	Power Supply Rejection Ratio		● 60	90		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
		$V_{\text{OUT}} = 0.1\text{V to } 4.9\text{V}$, $R_{\text{LOAD}} = 100\text{k}\Omega$	● 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		●	300	500	nA
PM	Phase Margin	$R_{\text{LOAD}} = 100\text{k}\Omega$, $C_{\text{LOAD}} = 60\text{pF}$		64		$^\circ$
GM	Gain Margin	$R_{\text{LOAD}} = 100\text{k}\Omega$, $C_{\text{LOAD}} = 60\text{pF}$		-10		dB
GBWP	Gain-Bandwidth Product	$f = 1\text{kHz}$		10		kHz
t_{s}	Settling Time, 1.5V to 3.5V, Unity Gain	0.1%		0.5		ms
		0.01%		0.55		
	Settling Time, 2.45V to 2.55V, Unity Gain	0.1%		0.075		
		0.01%		0.078		
SR	Slew Rate	$A_{\text{V}} = 1$, $V_{\text{OUT}} = 1.5\text{V to } 3.5\text{V}$, $C_{\text{LOAD}} = 60\text{pF}$, $R_{\text{LOAD}} = 100\text{k}\Omega$		6		$\text{mV}/\mu\text{s}$
FPBW	Full Power Bandwidth ^{Note 2}	$2V_{\text{P-P}}$		300		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 TP2111N with shutdown.

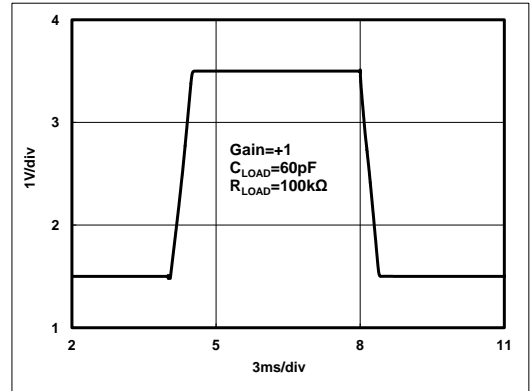
Note 2: Full power bandwidth is calculated from the slew rate $\text{FPBW} = \text{SR}/\pi \cdot V_{\text{P-P}}$.

Typical Performance Characteristics

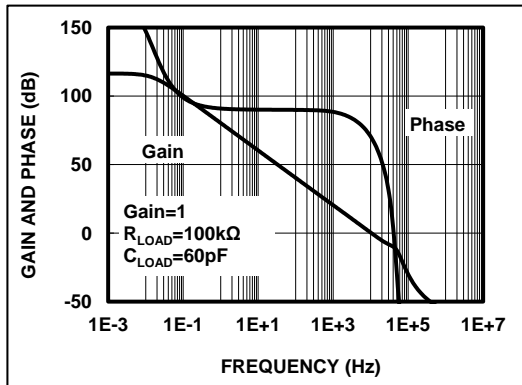
Small-Signal Step Response, 100mV Step



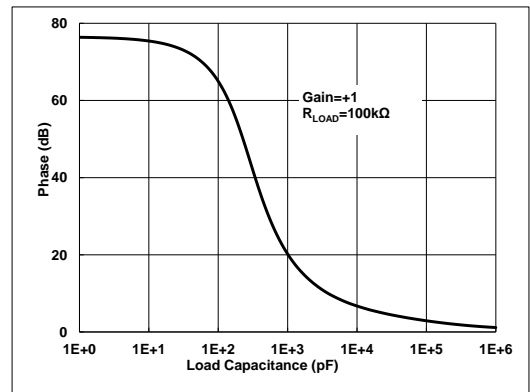
Large-Signal Step Response, 2V Step



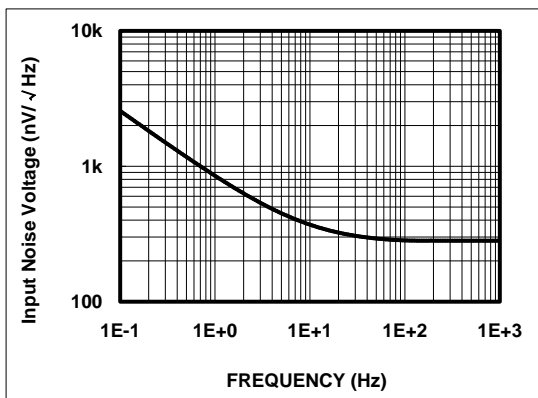
Open-Loop Gain and Phase



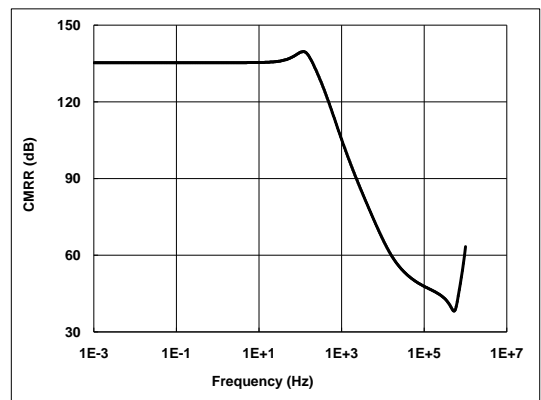
Phase Margin vs. C_LOAD (Stable for Any C_LOAD)



Input Voltage Noise Spectral Density



Common-Mode Rejection Ratio

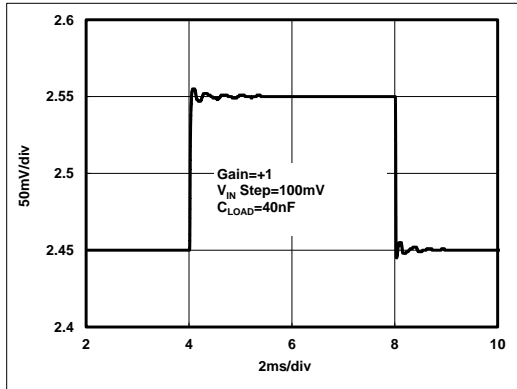


TP2111/TP2111N/TP2112/TP2114

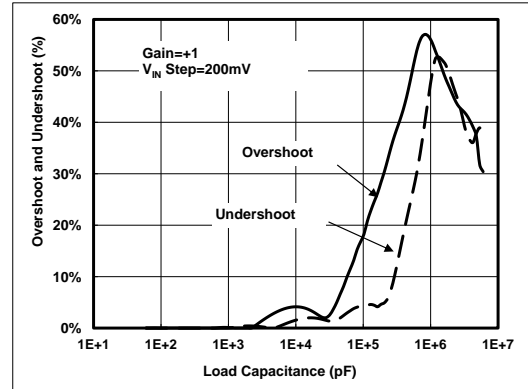
Nanopower 300nA, 1.8V, Rail-to-Rail Input/Output Op-amps

Typical Performance Characteristics

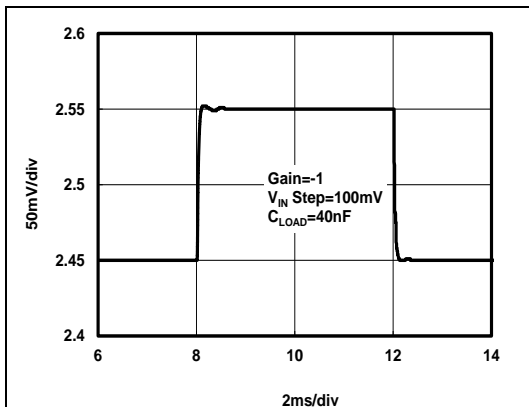
Over-Shoot Voltage, $C_{LOAD} = 40\text{nF}$, Gain = +1, $R_{FB}=100\text{k}\Omega$



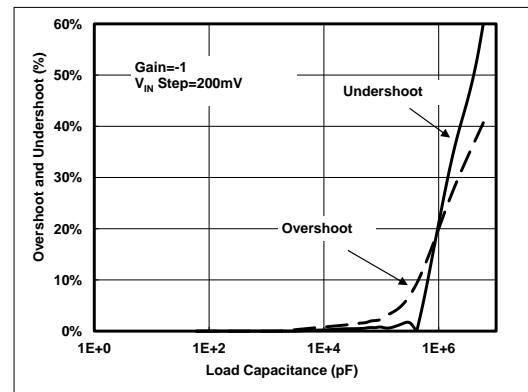
Over-Shoot % vs. C_{LOAD} , Gain = +1, $R_{FB} = 1\text{M}\Omega$



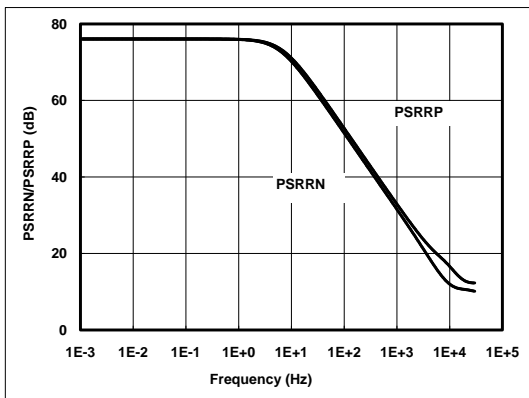
Over-Shoot Voltage, $C_{LOAD}=40\text{nF}$, Gain = -1, $R_{FB}=100\text{k}\Omega$



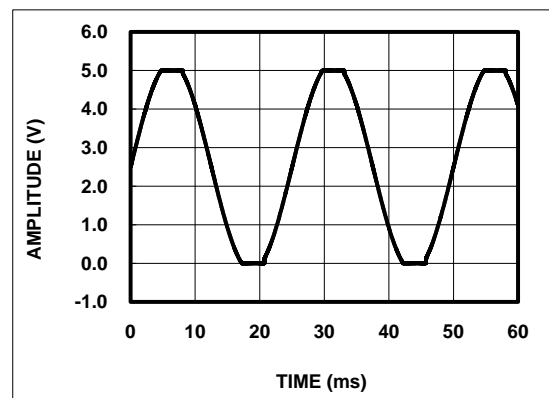
Over-Shoot % vs. C_{LOAD} , Gain = -1, $R_{FB} = 1\text{M}\Omega$



Power-Supply Rejection Ratio

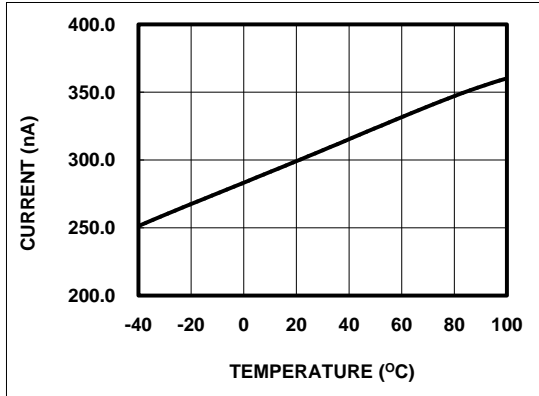


$V_{IN} = -0.2\text{V}$ to 5.7V , No Phase Reversal

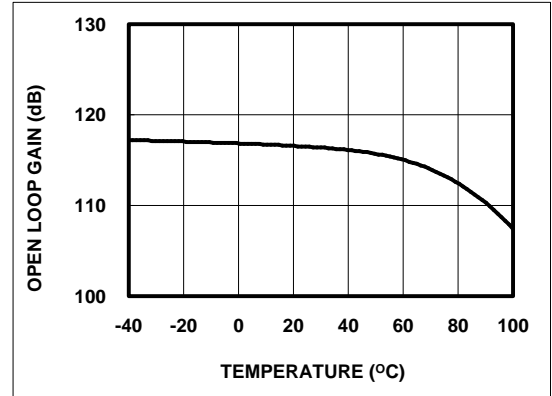


Typical Performance Characteristics

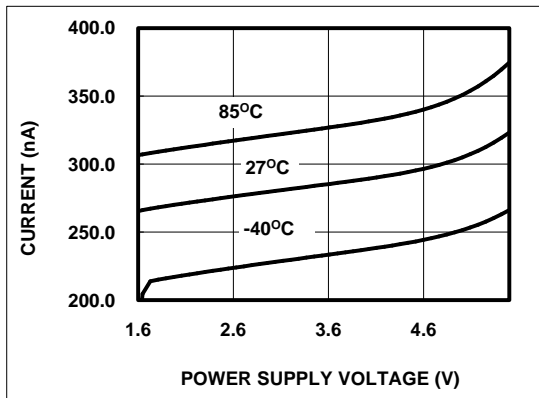
Quiescent Supply Current vs. Temperature



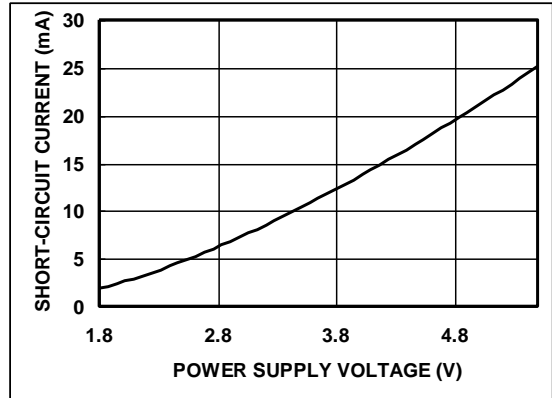
Open-Loop Gain vs. Temperature



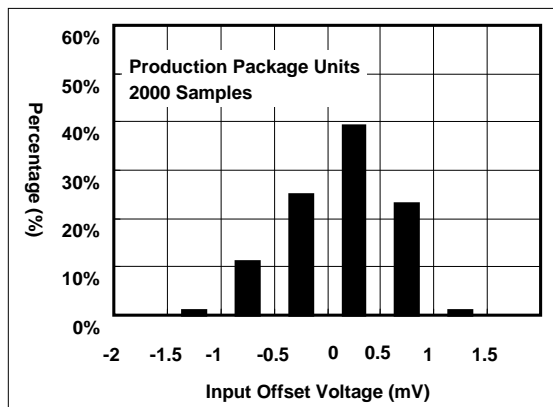
Quiescent Supply Current vs. Supply Voltage



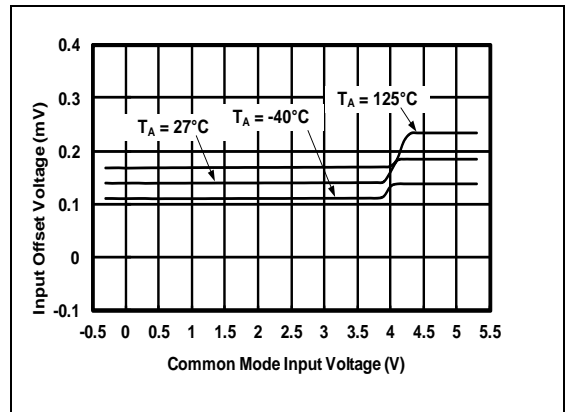
Short-Circuit Current vs. Supply Voltage



Input Offset Voltage Distribution



Input Offset Voltage vs. Common Mode Input Voltage

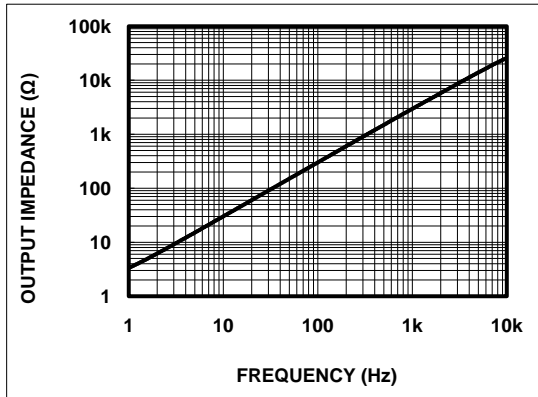


TP2111/TP2111N/TP2112/TP2114

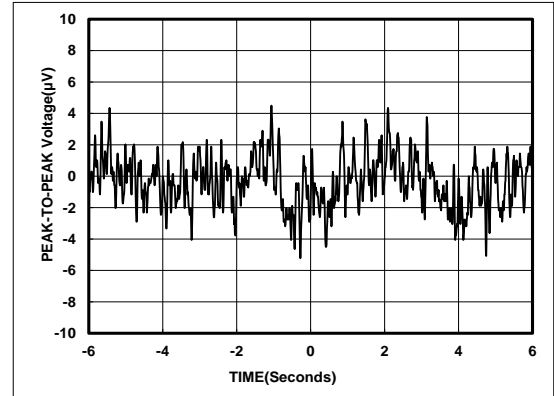
Nanopower 300nA, 1.8V, Rail-to-Rail Input/Output Op-amps

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 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 TP211x 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 TP211x family of operational amplifiers can operate with power supply voltages from 1.8V to 6.0V. Each amplifier draws only 300nA 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 TP211x 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 TP211x family provides a low input referred noise density of 265nV/√Hz at 1kHz. The voltage noise will grow slowly with the frequency in wideband range, and the input voltage noise is typically 10μV_{P-P} at the frequency of 0.1Hz to 10Hz.

Low Input Offset Voltage

The TP211x 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 TP211x family is a CMOS OPA family and features very low input bias current in fA 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 TP211x OPA’s input bias current at +27°C (±0.1fA, 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.

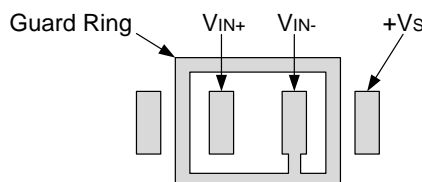


Figure 1

Ground Sensing and Rail to Rail Output

The TP211x 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.

TP2111/TP2111N/TP2112/TP2114

Nanopower 300nA, 1.8V, 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 TP211x 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 TP211x 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 TP211x 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.

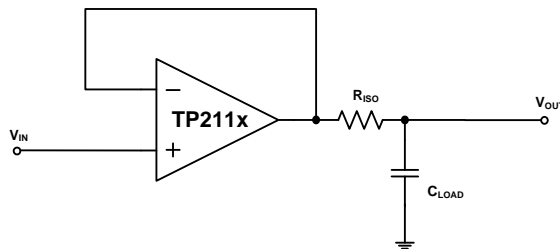


Figure 2

Power Supply Layout and Bypass

The TP211x 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 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.

BATTERY CURRENT SENSING

The Common Mode Input voltage Range of TP211x 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 (300nA, 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 below V_{DD} , within its Maximum Output Voltage Swing specification.

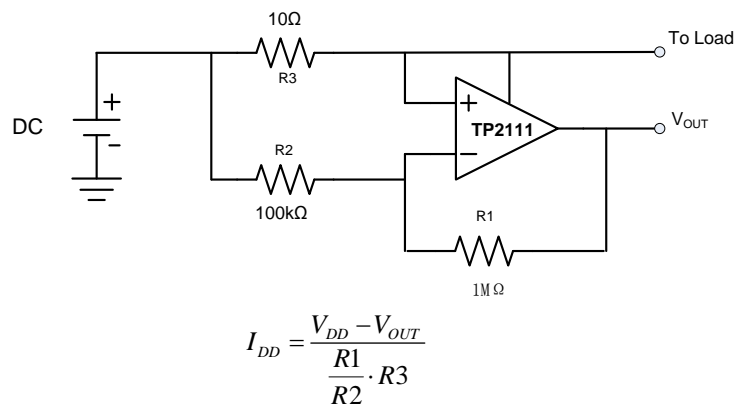


Figure 3

Instrumentation Amplifier

The TP211x OPA series is well suited for conditioning sensor signals in battery-powered applications. Figure 4 shows a two op-amp instrumentation amplifier, using the TP211x 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 $V_{DD}/2$.

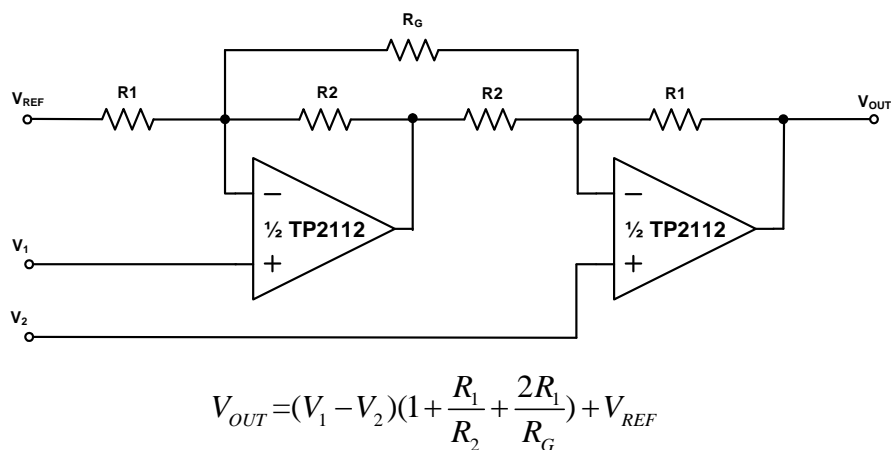


Figure 4

Buffered Chemical Sensor (pH) Probe

The TP211x OPA has input bias current in the fA range. This is ideal in buffering high impedance chemical sensors such as pH probe. As an example, the circuit in Figure 5 eliminates expansive low-leakage cables that that is required to connect pH probe to metering ICs such as ADC, AFE and/or MCU. A TP211x 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.

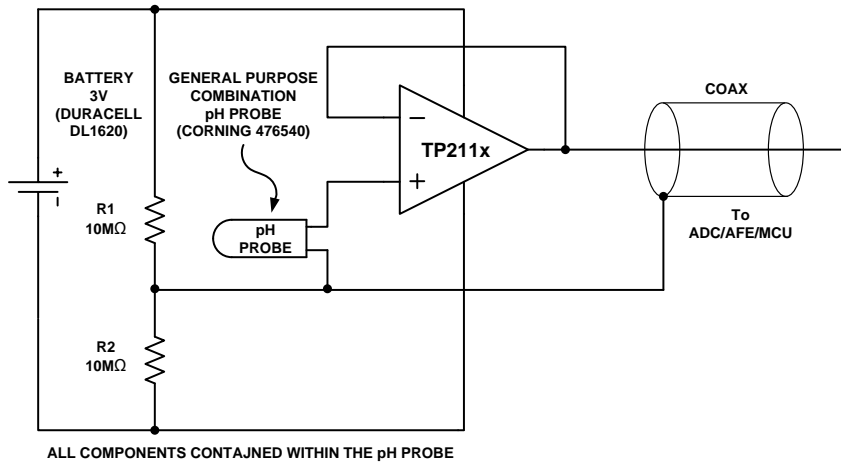


Figure 5: Buffer pH Probe

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 300nA 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.

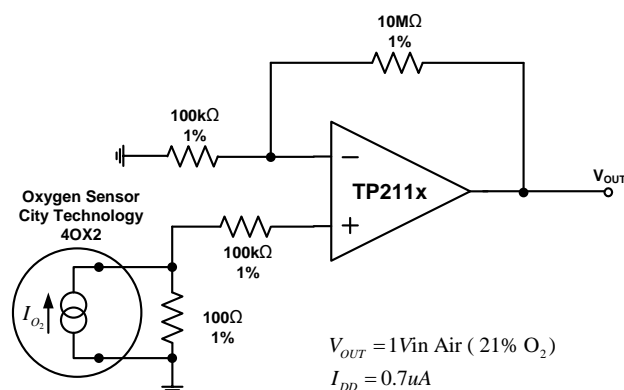
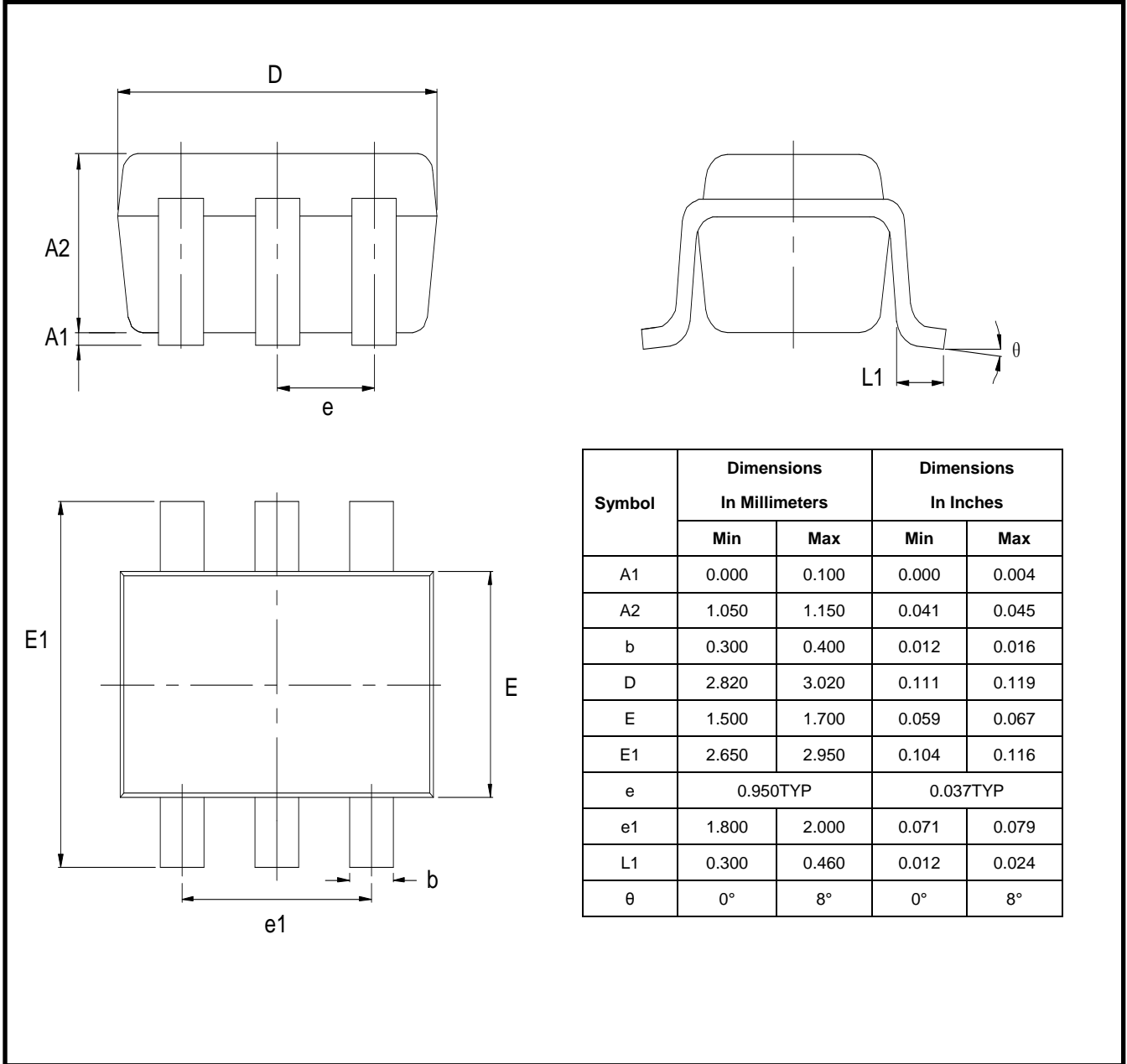


Figure 6

Package Outline Dimensions

SOT23-5 / SOT23-6

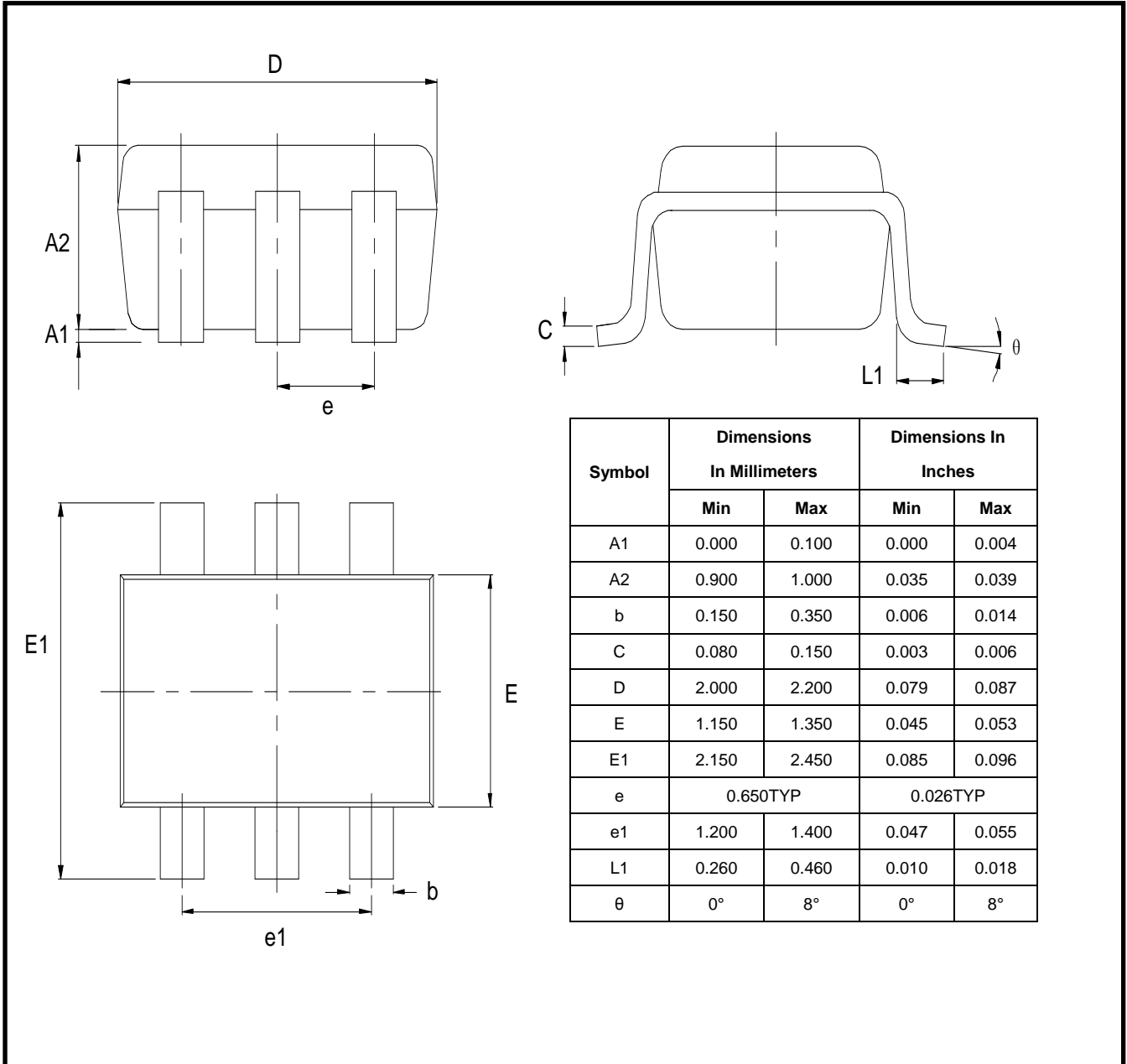


TP2111/TP2111N/TP2112/TP2114

Nanopower 300nA, 1.8V, Rail-to-Rail Input/Output Op-amps

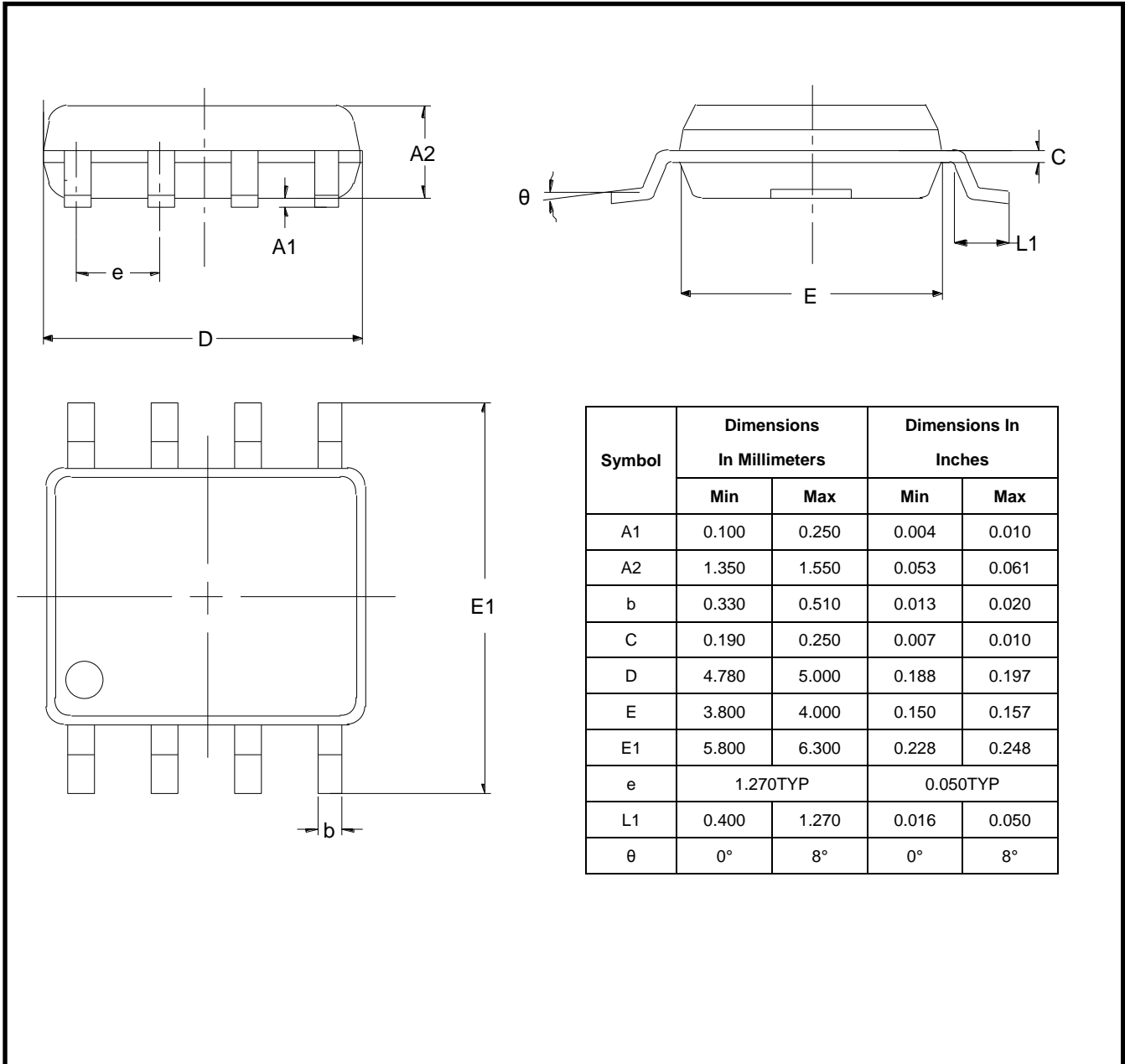
Package Outline Dimensions

SC-70-5 (SOT353)



Package Outline Dimensions

SO-8 (SOIC-8)

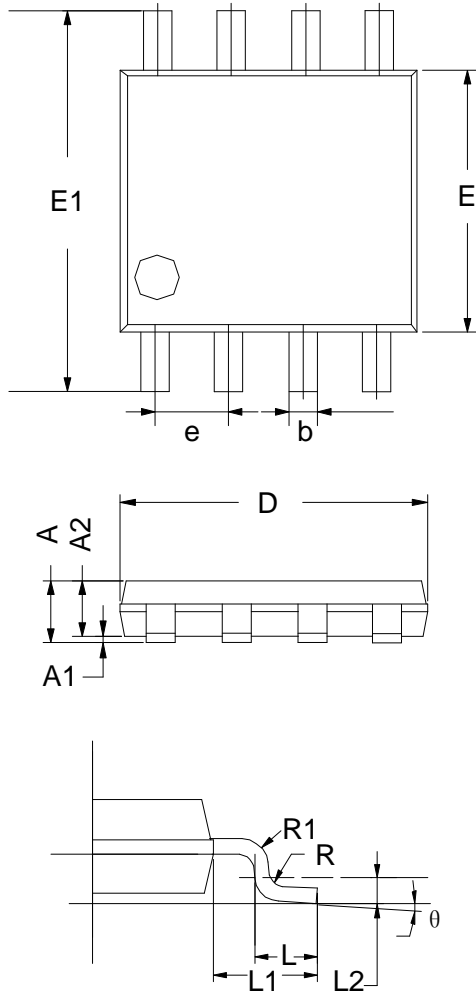


Package Outline Dimensions

TP2111/TP2111N/TP2112/TP2114

Nanopower 300nA, 1.8V, Rail-to-Rail Input/Output Op-amps

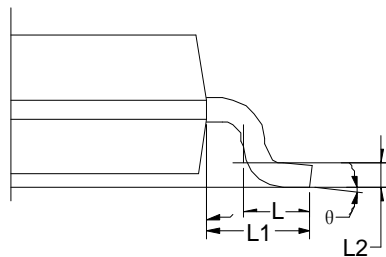
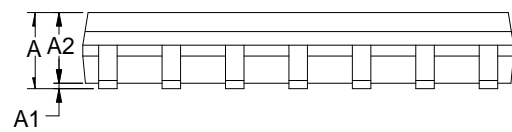
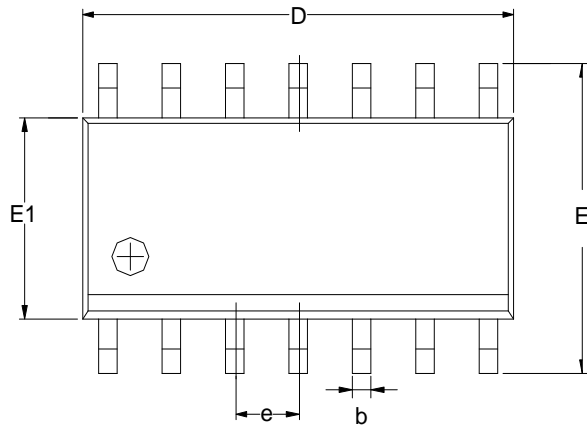
MSOP-8



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
theta	0°	6°	0°	6°

Package Outline Dimensions

SO-14 (SOIC-14)



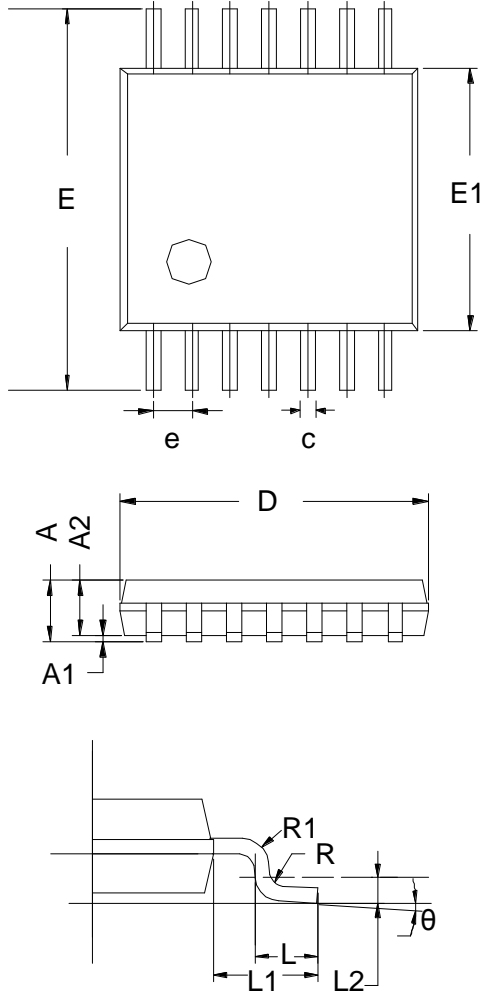
Symbol	Dimensions In Millimeters		
	MIN	TYP	MAX
A	1.35	1.60	1.75
A1	0.10	0.15	0.25
A2	1.25	1.45	1.65
b	0.36		0.49
D	8.53	8.63	8.73
E	5.80	6.00	6.20
E1	3.80	3.90	4.00
e	1.27 BSC		
L	0.45	0.60	0.80
L1	1.04 REF		
L2	0.25 BSC		
θ	0°		8°

TP2111/TP2111N/TP2112/TP2114

Nanopower 300nA, 1.8V, 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°