TEXAS INSTRUMENTS

TLV8544, TLV8541, TLV8542

SNOSD29B – DECEMBER 2016 – REVISED JUNE 2017

TLV854x 500-nA, RRIO, Nanopower Operational Amplifiers for Cost-Optimized Systems

1 Features

- For Cost-Optimized Systems
- Nanopower Supply Current: 500 nA per Channel
- Offset Voltage: 3.1 mV (maximum)
- TcVos: 0.8 µV/°C
- Gain Bandwidth: 8 kHz
- Unity-Gain Stable
- Low Input-Bias Current: 100 fA
- Wide Supply Range: 1.7 V to 3.6 V
- Rail-to-Rail Input and Output (RRIO)
- Temperature Range –40°C to +125°C
- Industry Standard Package
  - Quad in 14-pin TSSOP

2 Applications

- Motion Detectors Using PIR Sensors SNAA301
- Motion Detectors Using Microwave Sensors
- Gas Detectors
- Ionization Smoke Alarms
- Thermostats
- Remote Sensors, IoT (Internet of Things)
- Active RFID Readers and Tags
- Portable Medical Equipment
- Glucose Monitoring

3 Description

The TLV854x ultra-low-power operational amplifiers (op amps) are intended for cost-optimized sensing applications in wireless and low-power wired equipment. The TLV854x family of op amps minimize power consumption in equipment such as motion detecting security systems (like microwave and PIR motion sensing) where operational battery life is critical. They also have a carefully designed CMOS input stage, enabling very low, femto-ampere bias currents, thereby reducing I_{BIAS} and I_{OS} errors that would otherwise impact sensitive applications. Examples of these include transimpedance amplifier (TIA) configurations with megaohm feedback resistors, and high source impedance sensing applications. Additionally, built-in EMI protection reduces sensitivity to unwanted RF signals from sources such as mobile phones, WiFi, radio transmitters and tab readers.

Device Information(1)

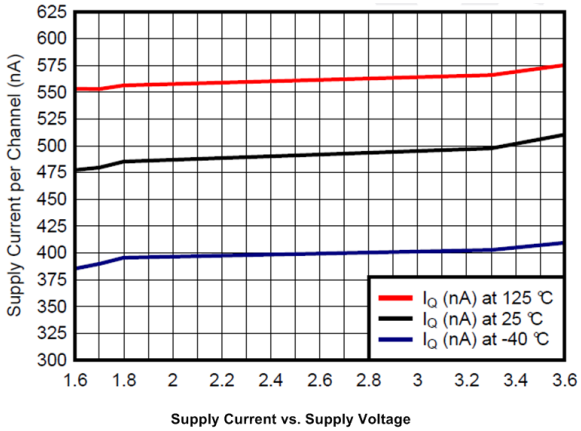
PART NUMBER	PACKAGE	BODY SIZE
TLV8541	SOT-23 (5)	2.90 mm x 1.60 mm
TLV8542	SOIC (8)	4.9 mm × 3.90 mm
TLV8544	TSSOP (14)	5.00 mm × 4.40 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

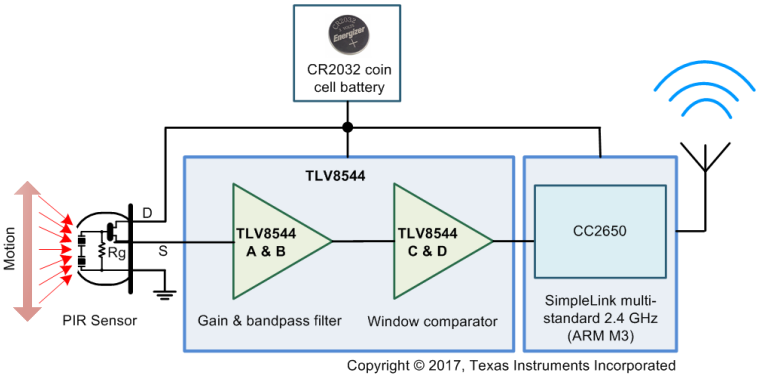
Nanopower Amplifiers Family

FAMILY	CHANNEL COUNT	I_Q PER CHANNEL	V_{OS} (maximum)	V_{SUPPLY}
TLV854x	1, 2, 4	500 nA	3.1 mV	1.7 to 3.6 V
TLV880x	1, 2	320 nA	4.5 mV	1.7 to 5.5 V
LPV81x	1, 2	425 nA	0.3 mV	1.6 to 5.5 V

Low Power PIR Motion Detector



Supply Current vs. Supply Voltage



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3.1 Description con't.

The TLV854x op amps operates with a single supply voltage down to 1.7 V supply, providing continuous performance in low battery situations over the extended temperature range of –40°C to +125°C. All versions are specified for operation from –40°C to 125°C. The TLV8541 (single version) is available in the 5-pin SOT-23 while the TLV8542 (dual version) is available in the 8-pin SOIC package. The 4-channel TLV8544 (quad version) is available in the industry standard 14-pin TSSOP package.

4 Revision History

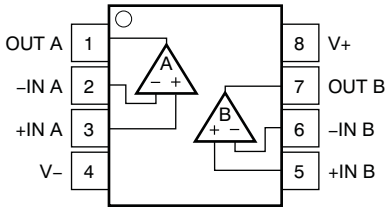
Changes from Revision A (March 2017) to Revision B	Page
• Added Advance Information TLV8542 to the TLV8544 Data Sheet	1

Changes from Original (December 2016) to Revision A	Page
• Changed Product Preview to Production Data release.	1

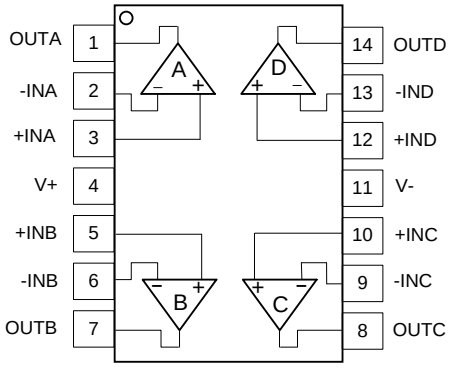
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5 Pin Configuration and Functions

TLV8542 8-Pin SOIC
D Package
Top View



PW Package
14-Pin TSSOP
Top View



Pin Functions: TLV8542 D

PIN		I/O	DESCRIPTION
NUMBER	NAME		
1	OUT A	O	Channel A Output
2	–IN A	I	Channel A Inverting Input
3	+IN A	I	Channel A Non-Inverting Input
4	V–	P	Positive (highest) power supply Negative (lowest) power supply
5	+IN B	I	Channel B Non-Inverting Input
6	–IN B	I	Channel B Inverting Input
7	OUT B	O	Channel B Output
8	V+	P	Positive (highest) power supply

Pin Functions: TLV8544 PW

PIN		I/O	DESCRIPTION
NUMBER	NAME		
1	OUTA	O	Channel A output
2	–INA	I	Channel A inverting input
3	+INA	I	Channel A non-inverting input
4	V+	P	Positive (highest) power supply
5	+INB	I	Channel B non-inverting input
6	–INB	I	Channel B inverting input
7	OUTB	O	Channel B output
8	OUTC	O	Channel C output
9	–INC	I	Channel C inverting input
10	+INC	I	Channel C non-inverting input
11	V–	P	Negative (lowest) power supply
12	+IND	I	Channel D non-inverting input
13	–IND	I	Channel D inverting input
14	OUTD	O	Channel D output

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6 Specifications

6.1 Absolute Maximum Ratings

Over operating free-air temperature range (unless otherwise noted) (1) (2) (3)

			MIN	MAX	UNIT
Supply voltage, V_S = (V+) – (V–)			–0.3	4	V
Input pins	Voltage	Common mode	(V–) – 0.3	(V+) + 0.3	V
		Differential	(V–) – 0.3	(V+) + 0.3	V
Input pins	Current		–10	10	mA
Output short current (4)			Continuous	Continuous	
Operating ambient temperature			–40	125	°C
Storage temperature, T_{stg}			–65	150	°C
Junction temperature				150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Input terminals are diode-clamped to the power-supply rails. Input signals that can swing more than 0.3 V beyond the supply rails must be current-limited to 10 mA or less.
(3) If Military/Aerospace specified devices are required, contact the Texas Instruments Sales Office/Distributors for availability and specifications.
(4) Short-circuit to ground.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 (1)	±1000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101 (2)	±250	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 500-V HBM is possible with the necessary precautions. Pins listed as ±2000 V may actually have higher performance.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 250-V CDM is possible with the necessary precautions. Pins listed as ±750 V may actually have higher performance.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

	MIN	NOM	MAX	UNIT
Supply voltage (V+ – V–)	1.7		3.6	V
Specified ambient temperature	–40		125	°C

6.4 Thermal Information

THERMAL METRIC (1)		TLV8544 PW (TSSOP) 14 PINS	TLV8542 D (SOIC) 8 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	124.5	141.6	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	52.7	85.7	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	66.2	84.7	°C/W
ψ_{JT}	Junction-to-top characterization parameter	7.3	36.3	°C/W
ψ_{JB}	Junction-to-board characterization parameter	65.7	84.0	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	N/A	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.

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6.5 Electrical Characteristics

T_A = 25°C, V_S = 1.8 V to 3.3 V, V_{CM} = V_{OUT} = V_S / 2, and R_L ≥ 10 MΩ to V_S / 2, unless otherwise noted.(1)

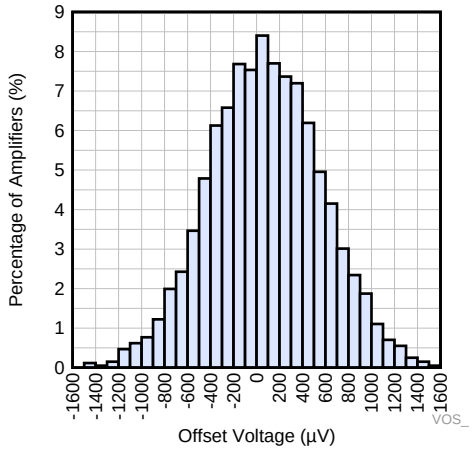
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OFFSET VOLTAGE						
V_{OS}	Input offset voltage	V_{CM} = V– , V_S = 1.8 V and 3.3 V	–3.1	See Plots	3.1	mV
		V_{CM} = V+, V_S = 1.8 V and 3.3 V	–3.4	See Plots	3.4	
dV_{OS}/dT	Input offset drift	V_{CM} = V–, T_A = –40°C to 125°C		0.8		µV/°C
PSRR	Power-supply rejection ratio	V_{CM} = V– , V_S =1.8 V and 3.3 V	66	90		dB
INPUT VOLTAGE RANGE						
V_{CM}	Common-mode voltage range	V_S = 3.3 V	0		3.3	V
CMRR	Common-mode rejection ratio	(V–) ≤ V_{CM} ≤ (V+), V_s = 3.3 V	60	80		dB
		(V–) ≤ V_{CM} ≤ (V+) – 1.2 V		90		
INPUT BIAS CURRENT						
I_B	Input bias current			100		fA
I_{OS}	Input offset current			100		fA
INPUT IMPEDANCE						
	Differential			2		pF
	Common mode			4		pF
NOISE						
E_n	Input voltage noise	f = 0.1 Hz to 10 Hz		8.6		µVp–p
e_n	Input voltage noise density	f = 1 kHz		264		nV/√Hz
OPEN-LOOP GAIN						
A_{OL}	Open-loop voltage gain	(V–) + 0.3 V ≤ V_O ≤ (V+) – 0.3 V, R_L = 100 kΩ to V^+/2		120		dB
OUTPUT						
V_{OH}	Voltage output swing from positive rail	R_L = 100 kΩ to V^+/2, V_S = 3.3 V	12			mV
V_{OL}	Voltage output swing from negative rail	R_L = 100 kΩ to V^+/2, V_S = 3.3 V			12	mV
I_{SC}	Short-circuit current	Sourcing, V_O to V–, $V_{IN(diff)}$ = 100 mV, V_S = 3.3 V		15		mA
		Sinking, V_O to V+, $V_{IN(diff)}$ = –100 mV, V_S = 3.3 V		30		
Z_O	Open loop output impedance	f = 1 kHz, I_O = 0 mA		8		kΩ
FREQUENCY RESPONSE						
GBP	Gain-bandwidth product	C_L = 20 pF, R_L = 10 MΩ		8		kHz
SR	Slew rate (10% to 90%)	G = 1, rising edge, C_L = 20 pF		3.5		V/ms
		G = 1, falling edge, C_L = 20 pF		4.5		
POWER SUPPLY						
$I_{Q–TLV8542}$	Quiescent Current, Per Channel (1)	V_{CM} = V–, I_O = 0 mA, V_S = 3.3 V		500	640	nA
$I_{Q–TLV8544}$	Quiescent current, per channel	V_{CM} = V–, I_O = 0 mA, V_S = 3.3 V		500	640	nA

(1) TLV8542 data is Advance Information and subject to change.

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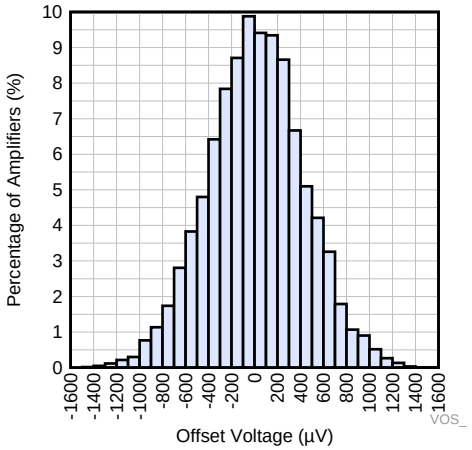
6.6 Typical Characteristics

TA = 25°C, R_L = 10 MΩ to V_S/2 ,C_L = 20 pF, V_{CM} = V_S / 2 V unless otherwise specified.



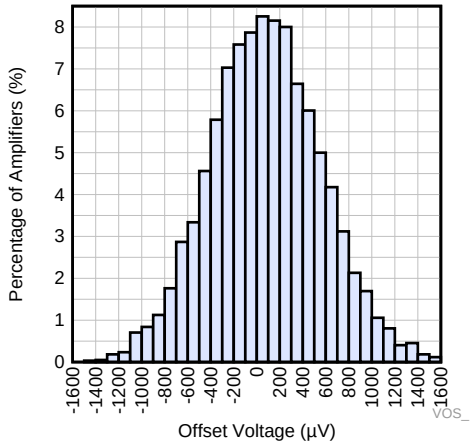
V_S = 1.8 V V_{CM} = V+ Data from 1500 4-channel devices

Figure 1. Offset Voltage Production Distribution



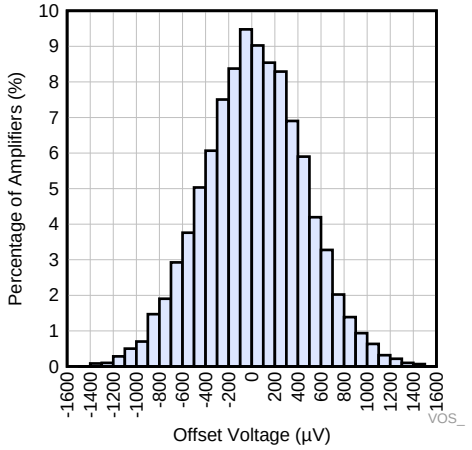
V_S = 1.8 V V_{CM} = V– Data from 1500 4-channel devices

Figure 2. Offset Voltage Production Distribution



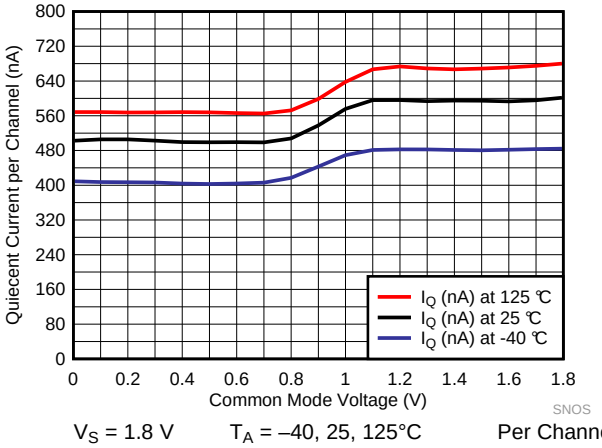
V_S = 3.3 V V_{CM} = V+ Data from 1500 4-channel devices

Figure 3. Offset Voltage Production Distribution



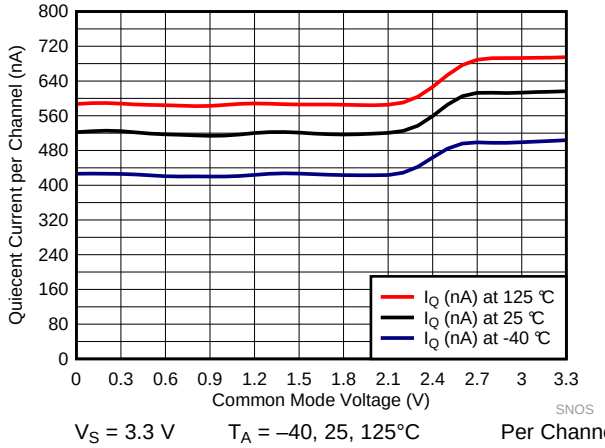
V_S = 3.3 V V_{CM} = V– Data from 1500 4-channel devices

Figure 4. Offset Voltage Production Distribution



V_S = 1.8 V T_A = –40, 25, 125°C Per Channel

Figure 5. Supply Current vs Common Mode Voltage



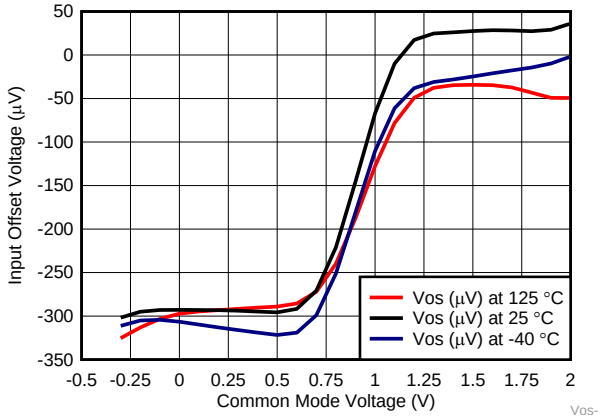
V_S = 3.3 V T_A = –40, 25, 125°C Per Channel

Figure 6. Supply Current vs Common Mode Voltage

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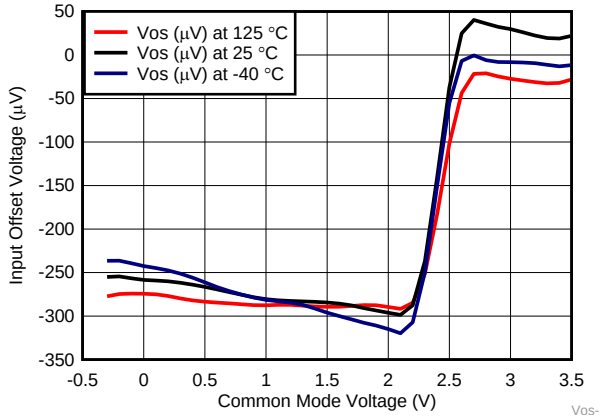
Typical Characteristics (continued)

TA = 25°C, R_L = 10 MΩ to V_S/2 ,C_L = 20 pF, V_{CM} = V_S / 2 V unless otherwise specified.



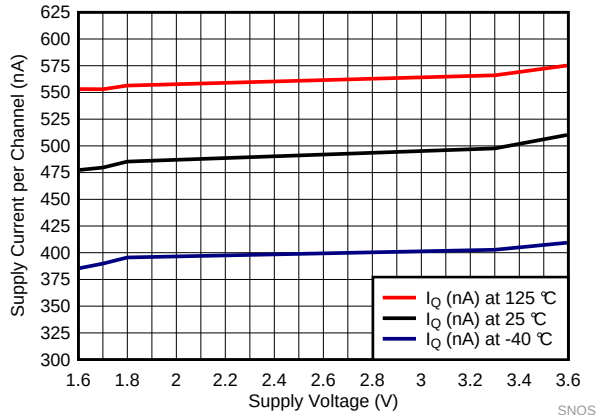
V_S = 1.8 V T_A = –40, 25, 125°C

Figure 7. Typical Offset Voltage vs Common Mode Voltage



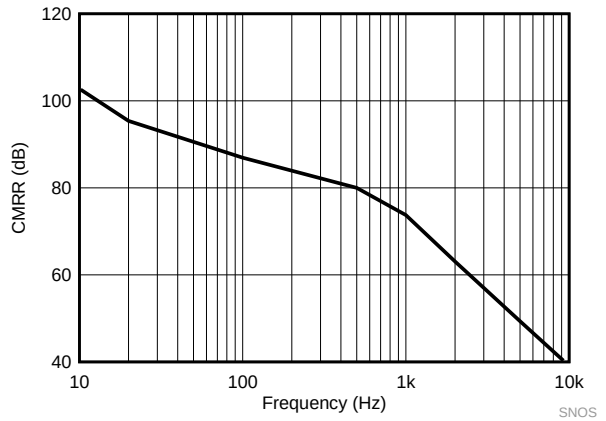
V_S = 3.3 V T_A = –40, 25, 125°C

Figure 8. Typical Offset Voltage vs Common Mode Voltage



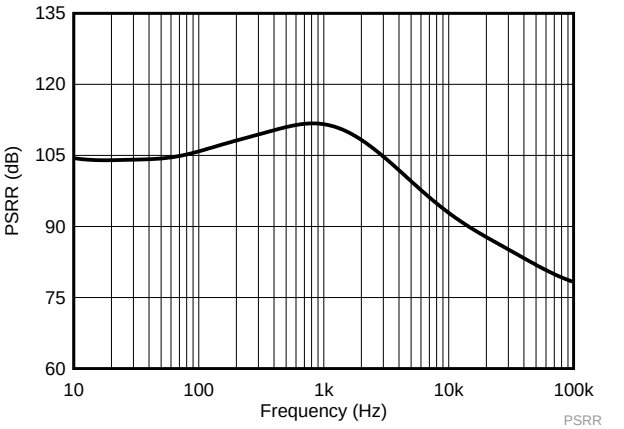
V_S = 1.6 to 3.6V T_A = –40, 25, 125°C V_{CM} = V-

Figure 9. Supply Current vs Supply Voltage, Low VCM



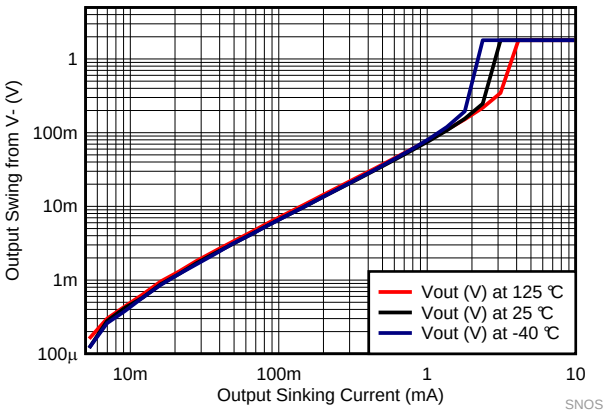
V_S= 3.3V T_A = 25°C

Figure 10. CMRR vs Frequency



V_S= 3.3V T_A = 25°C V_{CM} = V–

Figure 11. PSRR vs Frequency



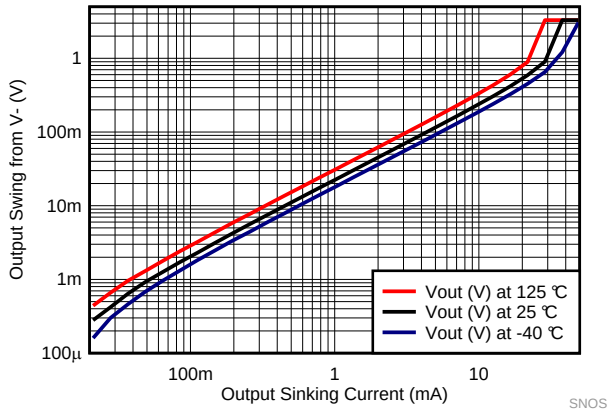
V_S = 1.8 V T_A = –40, 25, 125°C

Figure 12. Output Swing vs Sinking Current

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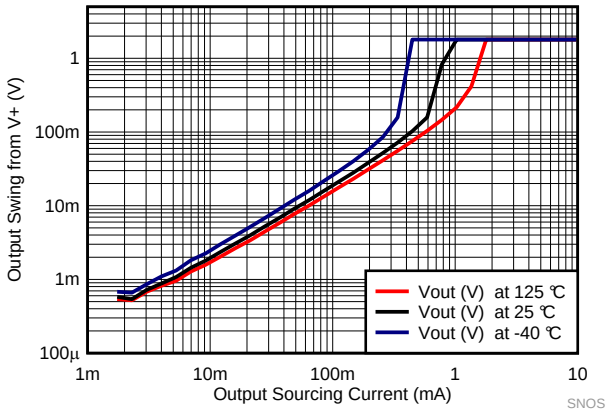
Typical Characteristics (continued)

TA = 25°C, R_L = 10 MΩ to V_S/2 ,C_L = 20 pF, V_{CM} = V_S / 2 V unless otherwise specified.



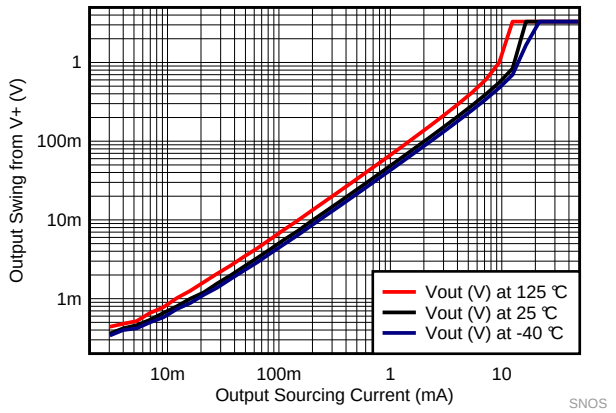
V_S = 3.3 V T_A = –40, 25, 125°C

Figure 13. Output Swing vs Sinking Current



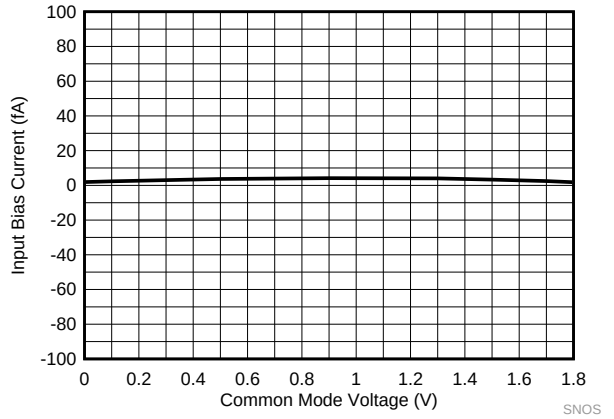
V_S = 1.8 V T_A = –40, 25, 125°C

Figure 14. Output Swing vs Sourcing Current



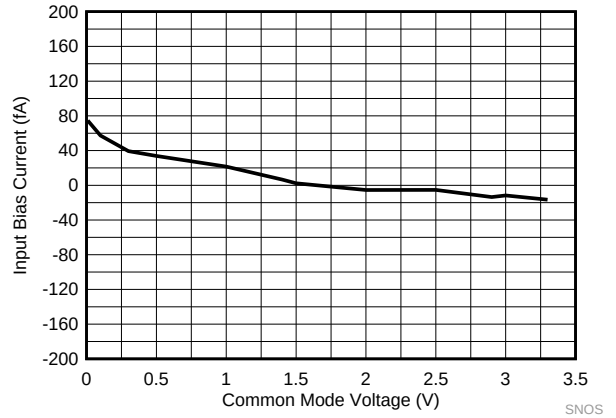
V_S = 3.3 V T_A = –40, 25, 125°C

Figure 15. Output Swing vs Sourcing Current



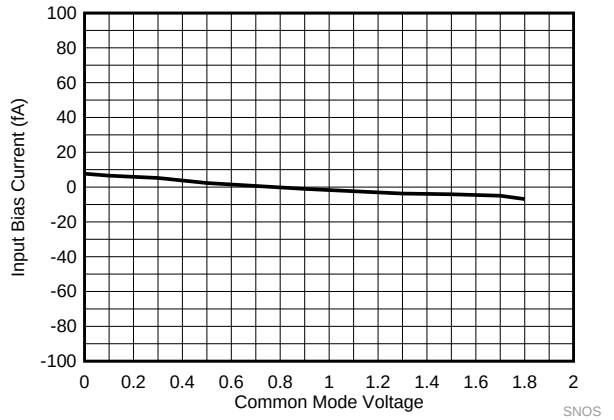
V_S = 1.8 V T_A = –40°C

Figure 16. Input Bias Current vs Common Mode Voltage



V_S = 3.3 V T_A = –40°C

Figure 17. Input Bias Current vs Common Mode Voltage



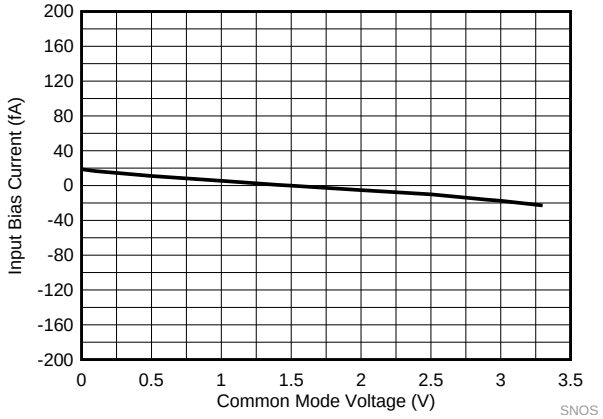
V_S = 1.8 V T_A = 25°C

Figure 18. Input Bias Current vs Common Mode Voltage

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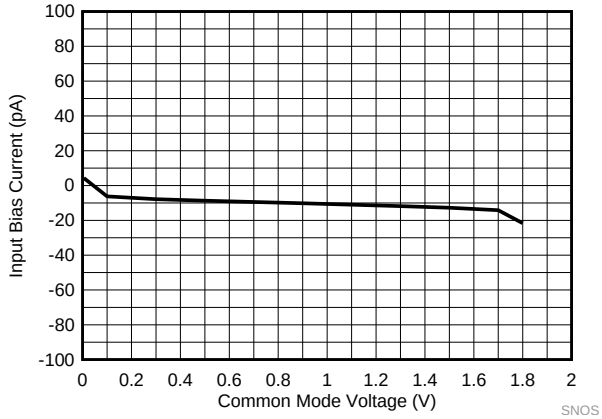
Typical Characteristics (continued)

TA = 25°C, R_L = 10 MΩ to V_S/2 ,C_L = 20 pF, V_{CM} = V_S / 2 V unless otherwise specified.



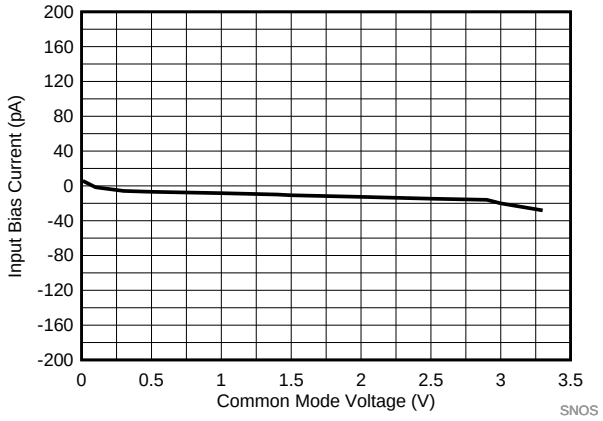
V_S = 3.3 V T_A = 25°C

Figure 19. Input Bias Current vs Common Mode Voltage



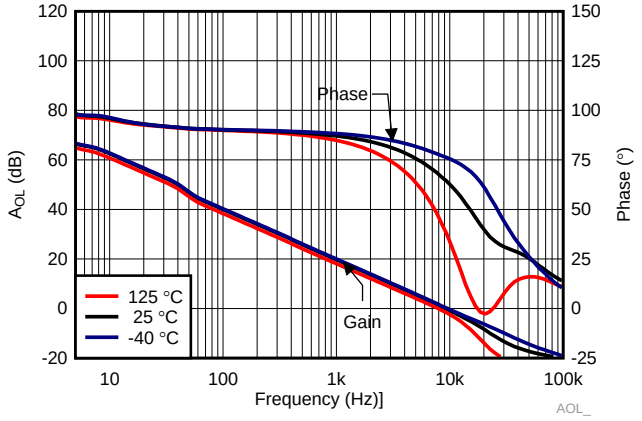
V_S= 1.8V T_A = 125°C

Figure 20. Input Bias Current vs Common Mode Voltage



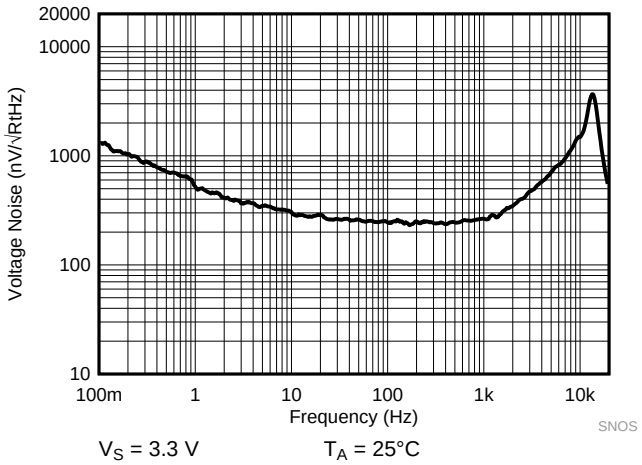
V_S = 3.3 V T_A = 125°C

Figure 21. Input Bias Current vs Common Mode Voltage



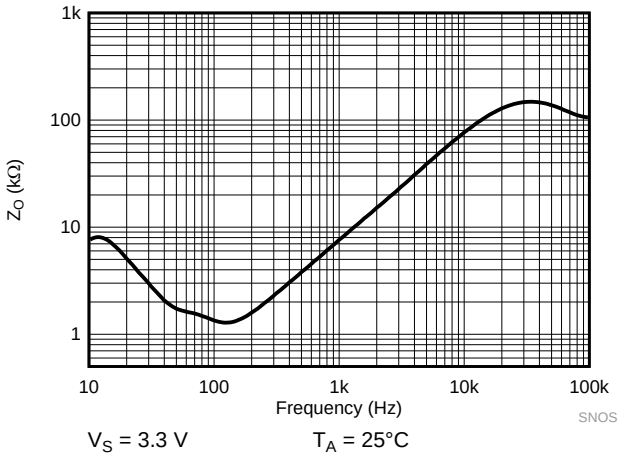
V_S = 3.3 V T_A = –40, 25, 125°C C_L = 50 pF

Figure 22. Open Loop Gain and Phase



V_S = 3.3 V T_A = 25°C

Figure 23. Input Voltage Noise vs Frequency



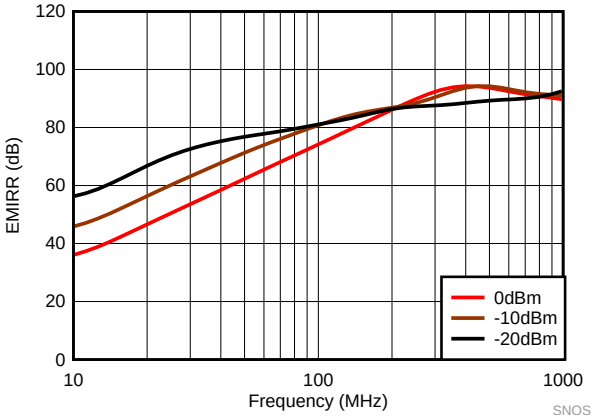
V_S = 3.3 V T_A = 25°C

Figure 24. Open Loop Output Impedance

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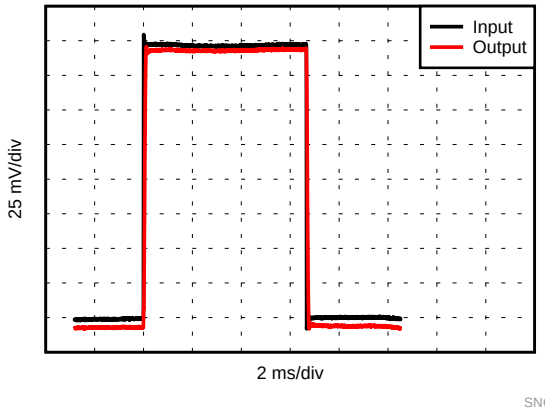
Typical Characteristics (continued)

TA = 25°C, R_L = 10 MΩ to V_S/2 ,C_L = 20 pF, V_{CM} = V_S / 2 V unless otherwise specified.



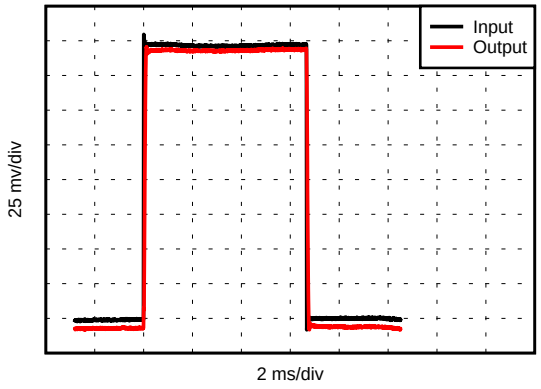
V_S = 3.3 V T_A = 25°C
A_V = 1

Figure 25. EMIRR Performance



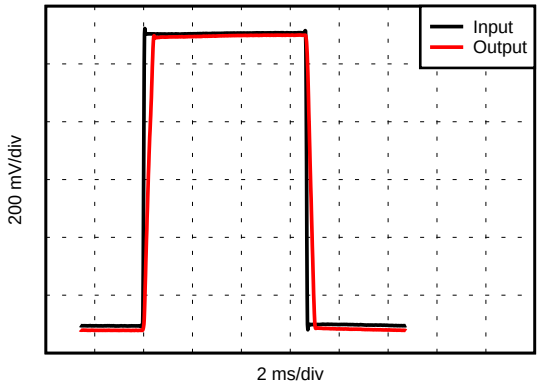
V_S = 1.8 V T_A = 25°C C_L = 50 pF
V_{IN} = 0.9 ± 0.1 V A_V = 1

Figure 26. Small Signal Pulse Response, 1.8 V



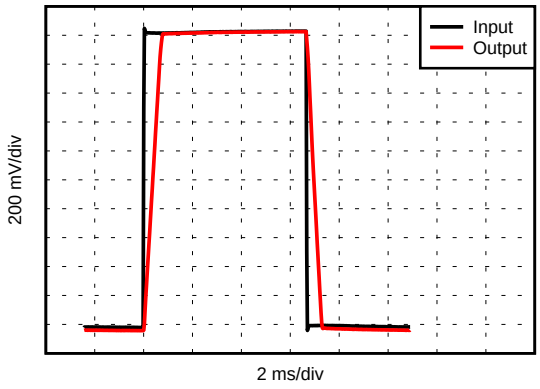
V_S = 3.3 V T_A = 25 °C C_L = 50 pF
V_{IN} = 1.65 ± 0.1 V A_V = 1

Figure 27. Small Signal Pulse Response, 3.3 V



V_S = 1.8 V T_A = 25°C C_L = 50 pF
V_{IN} = 0.9 ± 0.5 V A_V = 1

Figure 28. Large Signal Pulse Response, 1.8 V



V_S = 3.3 V T_A = 25°C C_L = 50 pF
V_{IN} = 1.65 ± 1 V A_V = 1

Figure 29. Large Signal Pulse Response, 3.3 V

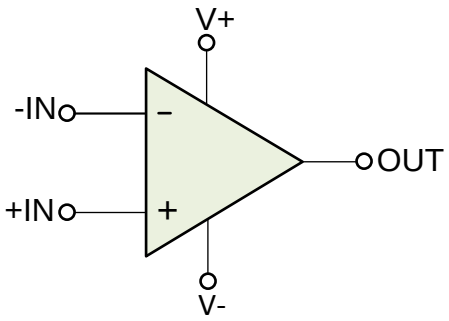
7 Detailed Description

7.1 Overview

The TLV854x amplifiers are unity-gain stable and can operate on a single supply, making them highly versatile and easy to use.

Parameters that vary significantly with operating voltages or temperature are shown in the *Typical Characteristics* curves.

7.2 Functional Block Diagram



7.3 Feature Description

The differential inputs of the TLV854x device consist of a non-inverting input (+IN) and an inverting input (–IN). The device amplifies only the difference in voltage between the two inputs, which is called the differential input voltage. The output voltage of the op-amps V_{OUT} are given by Equation 1:

$$V_{OUT} = A_{OL} [(+IN) – (–IN)] \quad (1)$$

where

- A_{OL} is the open-loop gain of the amplifier, typically around 100 dB.

7.4 Device Functional Modes

7.4.1 Rail-To-Rail Input

The input common-mode voltage range of the TLV854x extends to the supply rails. This is achieved with a complementary input stage — an N-channel input differential pair in parallel with a P-channel differential pair. The N-channel pair is active for input voltages close to the positive rail, typically (V+) – 800 mV to 200 mV above the positive supply, while the P-channel pair is on for inputs from 300 mV below the negative supply to approximately (V+) – 800 mV. There is a small transition region, typically (V+) – 1.2 V to (V+) – 0.8 V, in which both pairs are on. This 400-mV transition region can vary 200 mV with process variation. Within the 400-mV transition region PSRR, CMRR, offset voltage, offset drift, and THD may be degraded compared to operation outside this region.

7.4.2 Supply Current Changes Over Common Mode

Because of the ultra-low supply current, changes in common mode voltages cause a noticeable change in the supply current as the input stages transition through the transition region, as shown in Figure 30.

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Device Functional Modes (continued)

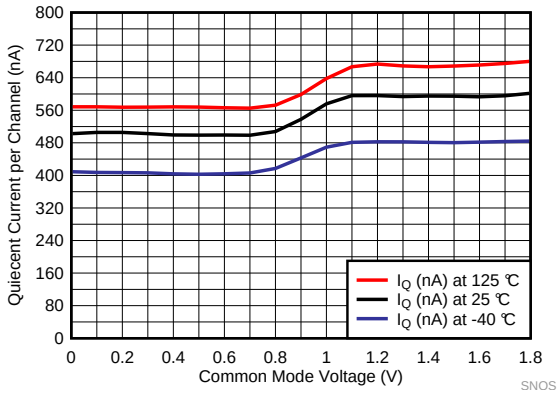


Figure 30. Supply Current Change Over Common Mode at 1.8 V

For the lowest supply current operation, keep the input common mode range between V– and 1 V below V+.

7.4.3 Design Optimization With Rail-To-Rail Input

In most applications, operation is within the range of only one differential pair. However, some applications can subject the amplifier to a common-mode signal in the transition region. Under this condition, the inherent mismatch between the two differential pairs may lead to degradation of the CMRR and THD. The unity-gain buffer configuration is the most problematic as it traverses through the transition region if a sufficiently wide input swing is required.

7.4.4 Design Optimization for Nanopower Operation

When designing for ultra-low power, choose system components carefully. To minimize current consumption, select large-value resistors. Any resistors react with stray capacitance in the circuit and the input capacitance of the operational amplifier (op amp). These parasitic RC combinations can affect the stability of the overall system. A feedback capacitor may be required to assure stability and limit overshoot or gain peaking.

When possible, use AC coupling and AC feedback to reduce static current draw through the feedback elements. Use film or ceramic capacitors because large electolytics may have static leakage currents in the tens to hundreds of nanoamps.

7.4.5 Common-Mode Rejection

The CMRR for the TLV854x is specified in two ways so the best match for a given application may be used. First, the CMRR of the device in the common-mode range below the transition region (V_{CM} < (V+) – 1.2 V) is given. This specification is the best indicator of the capability of the device when the application requires use of one of the differential input pairs. Second, the CMRR at V_S = 3.3 V over the entire common-mode range is specified.

7.4.6 Output Stage

The TLV854x output voltage swings 20 mV from rails at a 3.3-V supply, which provides the maximum possible dynamic range at the output. This is particularly important when operating on low supply voltages.

The TLV854x maximum output voltage swing defines the maximum swing possible under a particular output load.

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Device Functional Modes (continued)

7.4.7 Driving Capacitive Load

The TLV854x is internally compensated for stable unity-gain operation, with a 8-kHz typical gain bandwidth. However, the unity-gain follower is the most sensitive configuration-to-capacitive load. The combination of a capacitive load placed directly on the output of an amplifier along with the output impedance of the amplifier creates a phase lag, which reduces the phase margin of the amplifier. If the phase margin is significantly reduced, the response is under-damped, which causes peaking in the transfer and, when there is too much peaking, the op amp might start oscillating.

In order to drive heavy (> 50 pF) capacitive loads, use an isolation resistor, R_{ISO}, as shown in Figure 31. By using this isolation resistor, the capacitive load is isolated from the output of the amplifier. The larger the value of R_{ISO}, the more stable the amplifier will be. If the value of R_{ISO} is sufficiently large, the feedback loop is stable, independent of the value of C_L. However, larger values of R_{ISO} (e.g. 50 kΩ) result in reduced output swing and reduced output current drive.

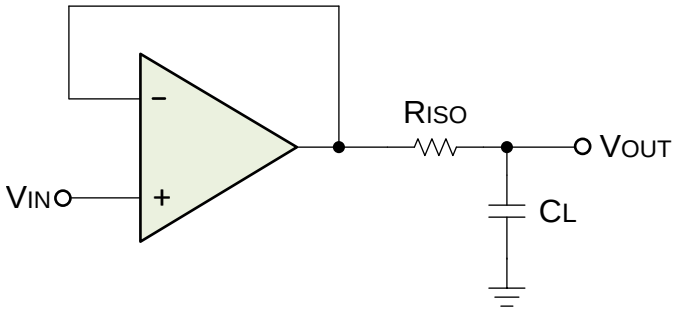


Figure 31. Resistive Isolation of Capacitive Load

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The TLV854x is a nanopower op amps that provides 8-kHz bandwidth with only 500-nA typical quiescent current per channel and near precision drift specifications at a low cost. These rail-to-rail input and output amplifiers are specifically designed for battery-powered applications. The input common-mode voltage range extends to the power-supply rails and the output swings to within millivolts of the rails, maintaining a wide dynamic range.

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8.2 Typical Application: Battery-Powered Wireless PIR Motion Detectors

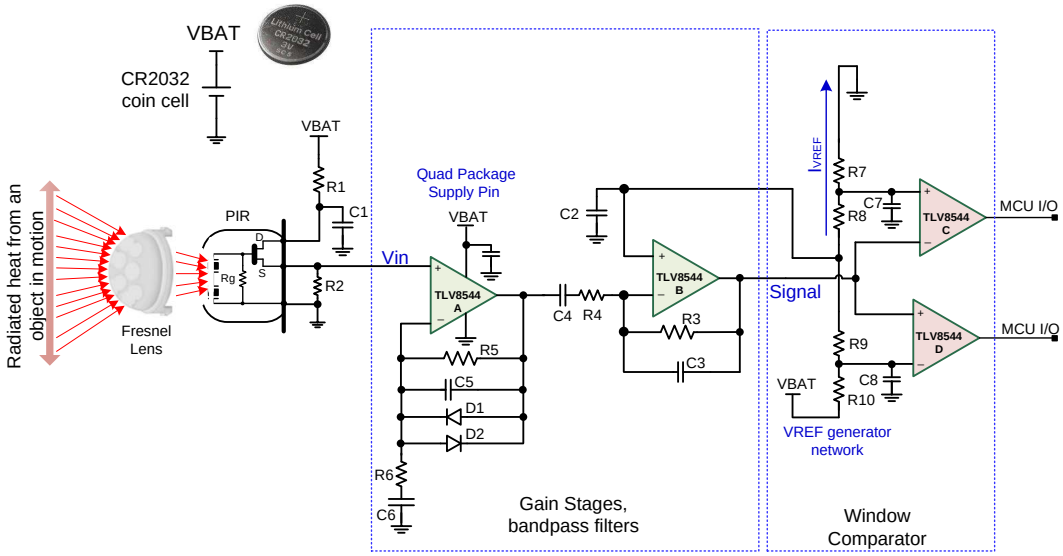


Figure 32. PIR Motion Detector Circuit

8.2.1 Design Requirements

Smart building automation systems employ a large number of various sensing nodes distributed throughout small, medium, and large infrastructures. The sensing nodes measure motion, temperature, vibration, and other parameters of interest. Wireless nodes are monitored in a central location. Because of the large number of distributed nodes , battery-operation and cost-optimized electronic components are required. Typically, the wireless nodes need to run on a single CR2032 coin battery for eight to ten years.

For more information see *Design of Ultra-Low Power Discrete Signal Conditioning Circuit for Battery-Power*, *Ultra-Low-Power Wireless PIR Motion Detector Reference Design* and *BOOSTXL-TLV8544PIR User's Guide*. The BOOSTXL-TLV8544PIR along with the companion CC2650 LaunchPad, LAUNCHXL-CC2650 can be obtained from the TI website for hands-on experiments.

8.2.2 Detailed Design Procedure

Referring to Figure 32, the TLV8544 4-channel op amp is powered directly by a 3.3-V CR2032 coin battery. The first two amplifier stages of the TLV8544 implement active filter functionality. The remaining two amplifiers of the TLV8544 are used for building a window comparator. The comparator flags the detection of a motion event to an ultra-low-power wireless microcontroller on the same board. Due to the higher gain in the filter stages and higher output noise from the sensor, it is necessary to optimize the placement of the high-frequency filter pole and the window comparator thresholds to avoid false detection.

The first two amplifiers (*A* and *B*) in the circuit are used in identical active bandpass filters with corner frequencies of 0.7 and 10.6 Hz. Each filter stage has a gain of about 220 V/V to account for the reduced sensitivity of the sensor due to the low current biasing of the PIR sensor. Considering the 8-kHz unity gain bandwidth (UGBW) product of the TLV8544, the bandwidth of each stage is limited to approximately 36 Hz. The above choice of cutoff frequencies give a relatively wide bandwidth to detect a person running in the field of view, yet narrow enough to limit the peak-to-peak noise at the output of the filters.

Amplifier *A* is a noninverting gain/filter stage providing the high input impedance needed to prevent loading of the sensor. The DC gain of the stage due to the presence of C6 is unity. Therefore, the sensor output provides the bias voltage needed at the *A* stage to avoid clipping of the lower cycle of the input signal. Diodes D1 and D2 limit the output signal, avoiding overdriving of the second stage and consequently placing a large charge on coupling capacitor C4, which helps with the recovery time.

8.2.2.1 Calculation of the Cutoff Frequencies and Gain of Stage A:

The low cutoff frequency of the bandpass filter in stage *A* is:

Typical Application: Battery-Powered Wireless PIR Motion Detectors (continued)

$$f_{Clow} = \frac{1}{2\pi \times R_6 \times C_6} \quad (2)$$

Choosing R6 = 6.81 kΩ and C6 = 33 µF, the low cutoff frequency is f_{Clow}= 0.71 Hz. The high cutoff frequency of the filter is:

$$f_{Chigh} = \frac{1}{2\pi \times R_5 \times C_5} \quad (3)$$

For R5 = 1.5 MΩ and C5 = 0.01 µF, the high cutoff frequency is f_{Chigh}= 10.6 Hz. The gain of the stage is:

$$G = 1 + \frac{R5}{R6} \quad (4)$$

Choosing R5 = 1.5 MΩ and R6 = 6.81 kΩ, the gain of the stage *A* is G = 221.26 V/V (46.9 dB).

8.2.2.2 Calculation of the Cutoff Frequencies and Gain of Stage B

As shown in Figure 32, amplifier *B* is an inverting bandpass filter and gain stage. Capacitor C4 creates an AC coupled path between the *A* and the *B* stages. Thus the signal level must be shifted at the input of the amplifier *B*. This is done by connecting a midpoint voltage of the reference voltage dividers comprising R10, R9, R8 and R7 to the non-inverting input of amplifier *B*, biasing the input signal to the mid-rail (1.65 V). A very large feedback resistor R3 is chosen to minimize the dynamic current due to presence of peak-to-peak noise voltage at the output of this stage.

The low cutoff frequency of the filter of the stage *B* is:

$$f_{Clow} = \frac{1}{2\pi \times R_4 \times C_4} \quad (5)$$

Choosing R4 = 68.1 kΩ and C4 = 3.3 µF, the low cutoff frequency is f_{Clow} = 0.71 Hz. The high cutoff frequency of the filter is:

$$f_{Chigh} = \frac{1}{2\pi \times R_3 \times C_3} \quad (6)$$

For R3 = 15 MΩ and C3 = 1000 pF, the high cutoff frequency is f_{Chigh}= 10.6 Hz. The gain of the stage is:

$$G = -\frac{R3}{R4} \quad (7)$$

For R3 = 15 MΩ and R4 = 68.1 kΩ, the gain is calculated |G| = 220.26 V/V (46.9 dB).

8.2.2.3 Calculation of the Total Gain of Stages A and B

The overall gain of the two stages *A* and *B* is: G_{Total}= G_A × G_B= 221.26 × 220.26 = 48810 V/V = 93.77 dB.

8.2.2.4 Window Comparator Stage

The signal from a moving object in front of the PIR sensor, after amplification and filtering, is connected to a window comparator. The comparator converts the analog signal to digital pulses for interrupting an on-board microcontroller unit (MCU), flagging detection of motion. A different approach is to digitize the analog signal continuously by an analog-to-digital converter (ADC) and implement the comparator functionality in the digital domain. This method has the advantage of enabling the post processing of the data to reduce the chance of false detection. However, continuous conversion and processing of data by the MCU increases the power consumption, lowering the lifetime of the battery substantially.

Rather than using a separate low-power comparator integrated circuits to implement the window comparator section of the circuit, the remaining op amps in the TLV8544 package are used to implement the comparator stage. Benefits of this approach include fewer components and thus reduced system cost.

Although an op amp can sometimes be used as a comparator, an amplifier cannot be used as a comparator interchangeably in all applications because of relatively long recovery time of the amplifier from output saturation and relatively long propagation delay due to internal compensation. Particularly, the nanopower op amps have very slow slew rate, limiting their usage as a comparator in only applications with very low frequency input signal. Fortunately, PIR sensor signals are relatively slow and this should not be an issue.

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Typical Application: Battery-Powered Wireless PIR Motion Detectors (continued)

The new TLV8544 device is particularly suitable for implementing a window comparator in a battery operated PIR motion detector application because of its rail-to-rail operation capability, relatively low offset voltage, low offset voltage drift, very low bias current, and nanopower consumption, all at an optimal cost. The input signal of the comparator stage in the presence of moving heat source across the sensor is shown in Figure 33. The signal is centered at mid-rail and can swing up or down from the center.

The window comparator is a combination of a non-inverting comparator implemented with amplifier *D* and an inverting comparator implemented with amplifier *C*, as shown in Figure 32.

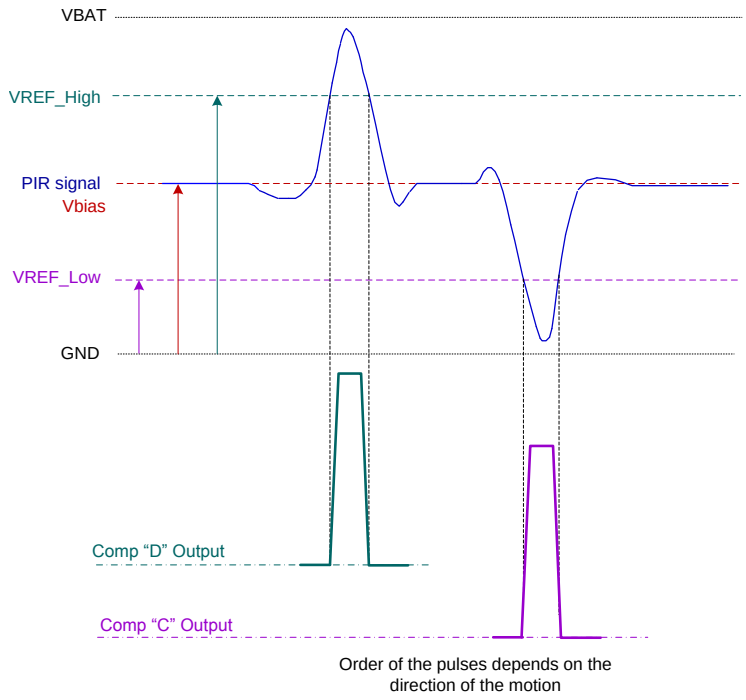


Figure 33. Ideal Amplified PIR Signal and the Output of the Window Comparator Circuit

8.2.2.5 Reference Voltages

Referring to Figure 32, the divider networks comprising R7, R8, R9, and R10, generate the reference voltages *VREF_High* and *VREF_Low* of the window comparator. The center point of the divider provides the bias voltage of the gain in the stage *B* through the connection to the noninverting input of the amplifier.

Due to the very low bias current of the TLV8544 device, it is possible to use very large values of resistors in the divider networks to minimize the current to ground through the resistors to a negligible amount. For R7 = R8 = R9 = R10 = 15 MΩ:

$$\text{VREF_High} = \left(\frac{R7 + R8 + R9}{R7 + R8 + R9 + R10}\right) V_{CC} = \frac{4.5 \times 10^6}{6 \times 10^6} \times V_{CC} = 0.75 \times V_{CC} \quad (8)$$

$$\text{VREF_Low} = \left(\frac{R7}{R8 + R9 + R10 + R7}\right) V_{CC} = \frac{1.5 \times 10^6}{6 \times 10^6} \times V_{CC} = 0.25 \times V_{CC} \quad (9)$$

Low leakage ceramic capacitors C7, and C8, maintain constant threshold voltages, preventing potential chatter at the output of the comparators. It should be noted that using cheap electrolytic capacitors must be avoided as they have high (many µA) leakage current. The comparator outputs stay low in the absence of motion across the sensor. In the presence of motion, comparators *C* and *D* generate *high* output pulses as shown in Figure 33. The order of the pulses depends on the direction of the motion in front of the sensor.

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Typical Application: Battery-Powered Wireless PIR Motion Detectors (continued)

8.2.3 Application Curve

Scope plots of the amplified PIR signal at the input of the noninverting comparator and the corresponding output signal are shown in Figure 34 and Figure 35. As the PIR signal (blue line) crosses the VREF_High threshold, the output of the comparator switches from the cutoff (slightly higher than ground) state to the saturation state (slightly lower than V_{BAT} = 3.3 V). Depending on the speed of the object, the PIR signal peaks to its maximum and roles off within several seconds. When the signal crosses the VREF_High threshold on the way down, the output of the noninverting amplifier toggles back to the cutoff region (low).

The data for plot of Figure 34 was captured using the BOOSTXL-TLV8544PIR board. Because the motion was created at very close proximity of the sensor on the booster board used to collect the data, the signal was limited by the diode in the first stage as shown in the plot.

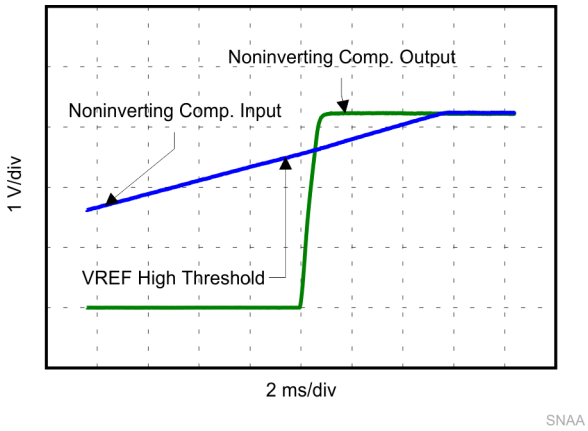


Figure 34. Noninverting Comparator Input and Output Signals

Referring to Figure 34, the output of the inverting comparator during the lower cycle of the PIR signal switches form the cutoff region to the saturation region as the input signal crosses the VREF_Low threshold.

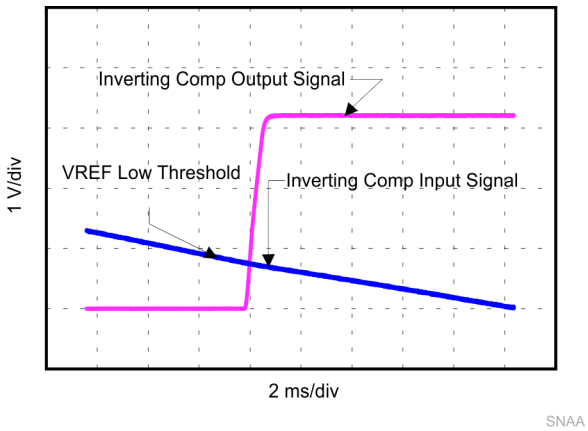


Figure 35. Noninverting Comparator Input and Output Signals

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8.3 Typical Application: 60-Hz Twin T Notch Filter

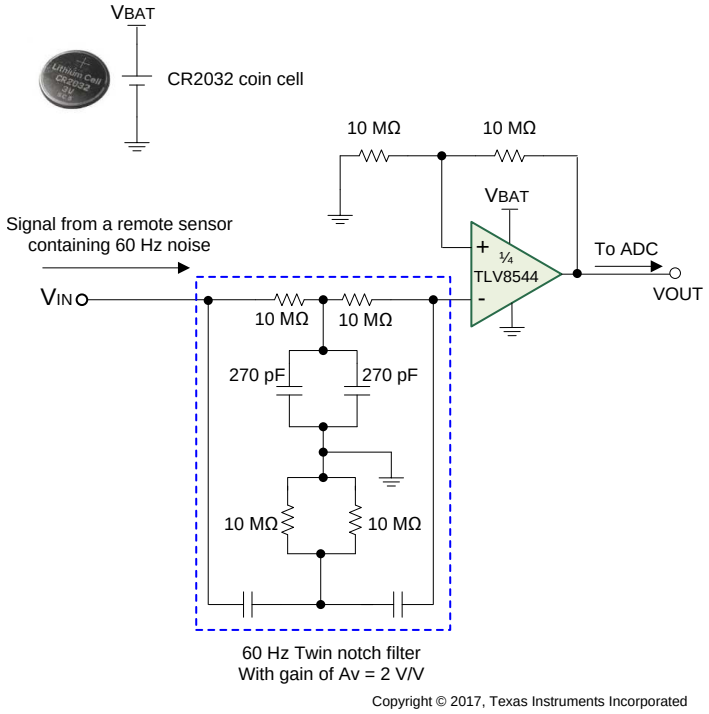


Figure 36. 60 Hz-Notch Filter

8.3.1 Design Requirements

Small signals from transducers in remote and distributed sensing applications commonly suffer strong 60-Hz interference from AC power lines. The circuit of Figure 36 filters out (notches out) the 60 Hz and provides a system gain of A_V = 2 V/V for the sensor signal represented by a 1-kHz sine wave. Similar stages may be cascaded to remove 2nd and 3rd harmonics of 60 Hz. Thanks to the nanopower consumption of the TLV8544, even five such circuits can run for 9.5 years from a small CR2032 lithium cell. These batteries have a nominal voltage of 3 V and an end of life voltage of 2 V. With an operating voltage from 1.7 V to 3.6 V the TLV8544 device can function over this voltage range.

8.3.2 Detailed Design Procedure

The notch frequency is set by:

$$F_0 = 1 / 2\pi RC. \quad (10)$$

To achieve a 60-Hz notch use R = 10 MΩ and C = 270 pF. If eliminating 50-Hz noise, use R = 11.8 MΩ and C = 270 pF.

The twin T notch filter works by having two separate paths from V_{IN} to the input of the amplifier. A low-frequency path through the series input resistors and another separate high-frequency path through the series input capacitors. However, at frequencies around the notch frequency, the two paths have opposing phase angles, and the two signals tend to cancel at the input of the amplifier.

To ensure that the target center frequency is achieved and to maximize the notch depth (Q factor) the filter must be as balanced as possible. To obtain circuit balance, while overcoming limitations of available standard resistor and capacitor values, use passives in parallel to achieve the 2C and R/2 circuit requirements for the filter components that connect to ground.

To make sure passive component values stay as expected, clean the board with alcohol, rinse with deionized water, and air dry. Make sure board remains in a relatively low humidity environment to minimize moisture which may increase the conductivity of board components. Also large resistors come with considerable parasitic stray capacitance which effects can be reduced by cutting out the ground plane below components of concern.

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Typical Application: 60-Hz Twin T Notch Filter (continued)

Large resistors are used in the feedback network to minimize battery drain. When designing with large resistors, resistor thermal noise, op amp current noise, as well as op-amp voltage noise, must be considered in the noise analysis of the circuit. The noise analysis for the circuit in Figure 36 can be done over a bandwidth of 2 kHz, which takes the conservative approach of overestimating the bandwidth (TLV8544 typical GBW/A_V is lower, where A_V is the gain of the system). The total noise at the output is approximately 800 µVpp, which is excellent considering the total consumption of the circuit is only 500 nA per channel. The dominant noise terms are op-amp voltage noise, current noise through the feedback network (430 µVp-p), and current noise through the notch filter network (280 µVp-p). Thus the total noise of the circuit is below 1/2 LSB of a 10-bit system with a 2-V reference, which is 1 mV.

8.3.3 Application Curve

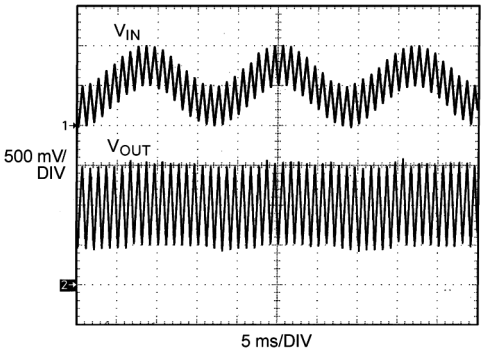


Figure 37. 60-Hz Notch Filter Waveform

8.4 Dos and Don'ts

Do properly bypass the power supplies.

Do add series resistance to the output when driving capacitive loads, particularly cables, multiplexers, and ADC inputs.

Do add series current limiting resistors and external Schottky clamp diodes if input voltage is expected to exceed the supplies. Limit the current to 1 mA or less (1 KΩ per volt).

9 Power Supply Recommendations

The TLV854x is specified for operation from 1.7 V to 3.6 V (±0.85 V to ±1.8 V) over a –40°C to +125°C temperature range. Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in the *Typical Characteristics*.

CAUTION

Supply voltages larger than 3.6 V can permanently damage the device.

For proper operation, the power supplies must be properly decoupled. For decoupling the supply lines it is suggested that 100-nF capacitors be placed as close as possible to the op-amp power supply pins. For single supply, place a capacitor between V+ and V– supply leads. For dual supplies, place one capacitor between V+ and ground and one capacitor between V– and ground.

Low bandwidth nanopower devices do not have good high frequency (> 1 kHz) AC PSRR rejection against high-frequency switching supplies and other 1-kHz and above noise sources, so extra supply filtering is recommended if kilohertz or above noise is expected on the power supply lines.

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10 Layout

10.1 Layout Guidelines

- The V+ pin must be bypassed to ground with a low ESR capacitor.
- The optimum placement is closest to the V+ and ground pins.
- Take care to minimize the loop area formed by the bypass capacitor connection between V+ and ground.
- Connect the ground pin to the PCB ground plane at the pin of the device.
- Place the feedback components as close as possible to the device to minimize stray impedance.

10.2 Layout Example

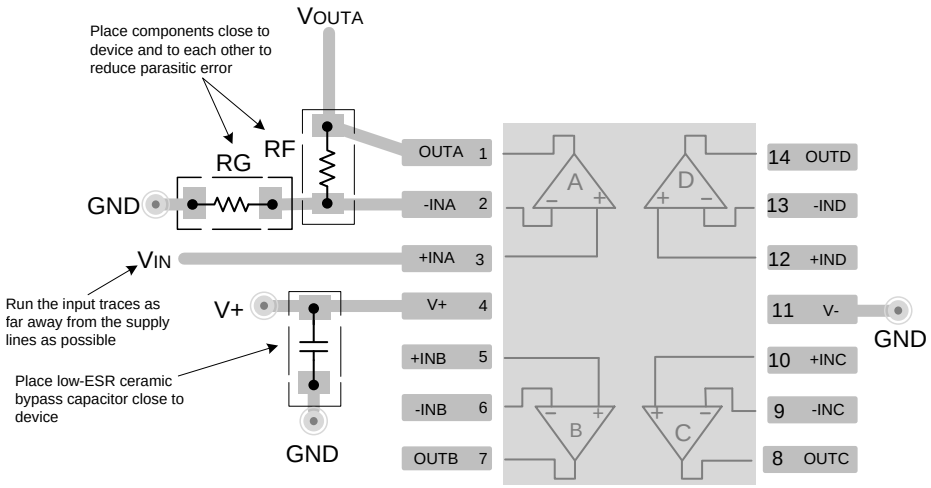


Figure 38. Layout Example of a Typical Dual Channel Package (Top View)

11 Device and Documentation Support

11.1 Device Support

11.1.1 Development Support

TINA-TI SPICE-Based Analog Simulation Program

DIP Adapter Evaluation Module

TI Universal Operational Amplifier Evaluation Module

TI FilterPro Filter Design Software

11.2 Documentation Support

11.2.1 Related Documentation

For related documentation, see the following:

- *AN-1798 Designing with Electro-Chemical Sensors*
- *AN-1803 Design Considerations for a Transimpedance Amplifier*
- *AN-1852 Designing With pH Electrodes*
- *Compensate Transimpedance Amplifiers Intuitively*
- *Transimpedance Considerations for High-Speed Operational Amplifiers*
- *Noise Analysis of FET Transimpedance Amplifiers*
- *Circuit Board Layout Techniques*
- *Handbook of Operational Amplifier Applications*

11.3 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to order now.

Table 1. Related Links

PARTS	PRODUCT FOLDER	ORDER NOW	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
TLV8544	Click here	Click here	Click here	Click here	Click here
TLV8541	Click here	Click here	Click here	Click here	Click here
TLV8542	Click here	Click here	Click here	Click here	Click here

11.4 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.5 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.6 Trademarks

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11.6 Trademarks (continued)

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11.7 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

11.8 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

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12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
PTLV8542DR	ACTIVE	SOIC	D	8	2500	TBD	Call TI	Call TI	-40 to 125		Samples
TLV8542DR	PREVIEW	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	TL8542	
TLV8544PWR	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	TL8544	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

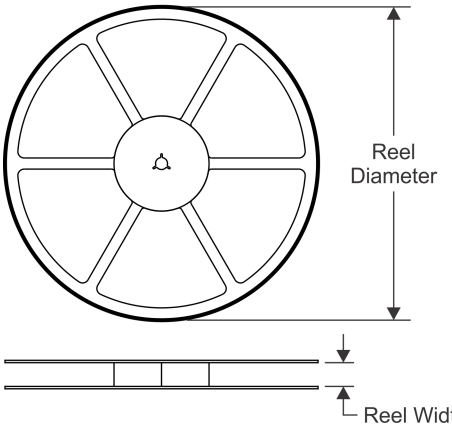
(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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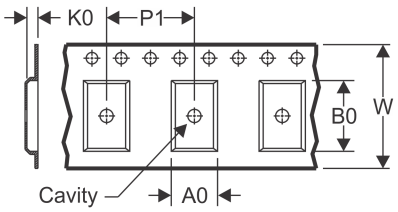
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

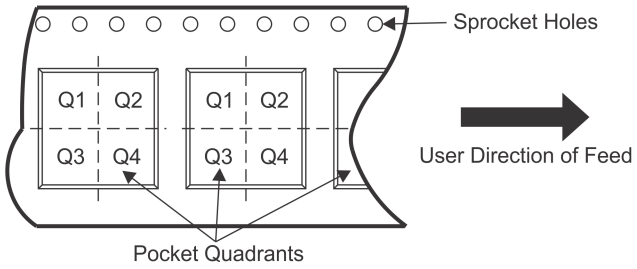


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

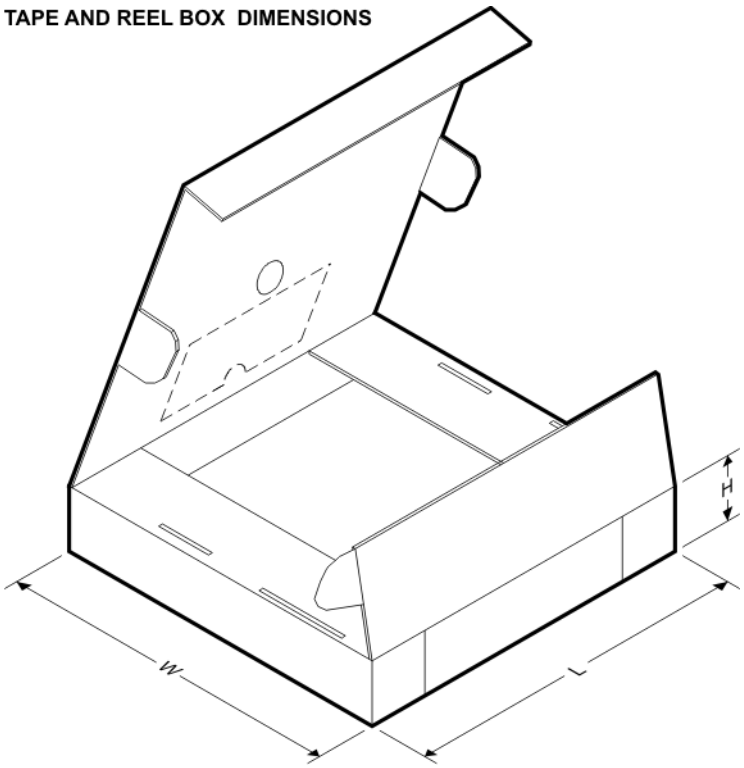
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TLV8544PWR	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1

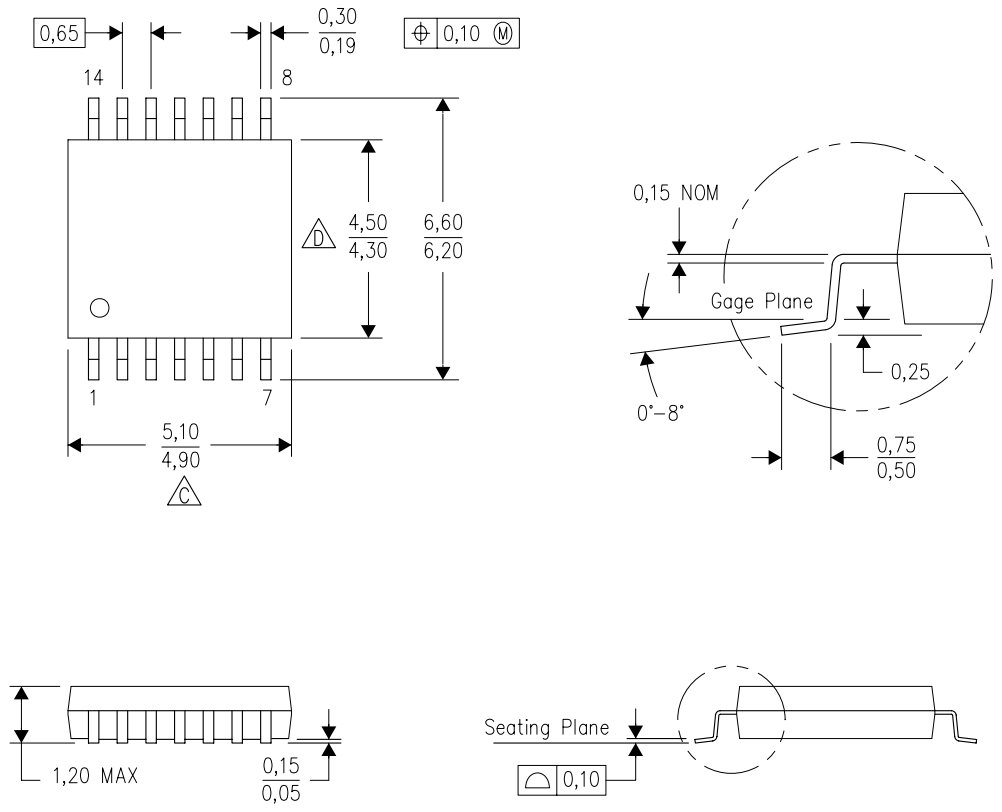
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TLV8544PWR	TSSOP	PW	14	2000	367.0	367.0	35.0

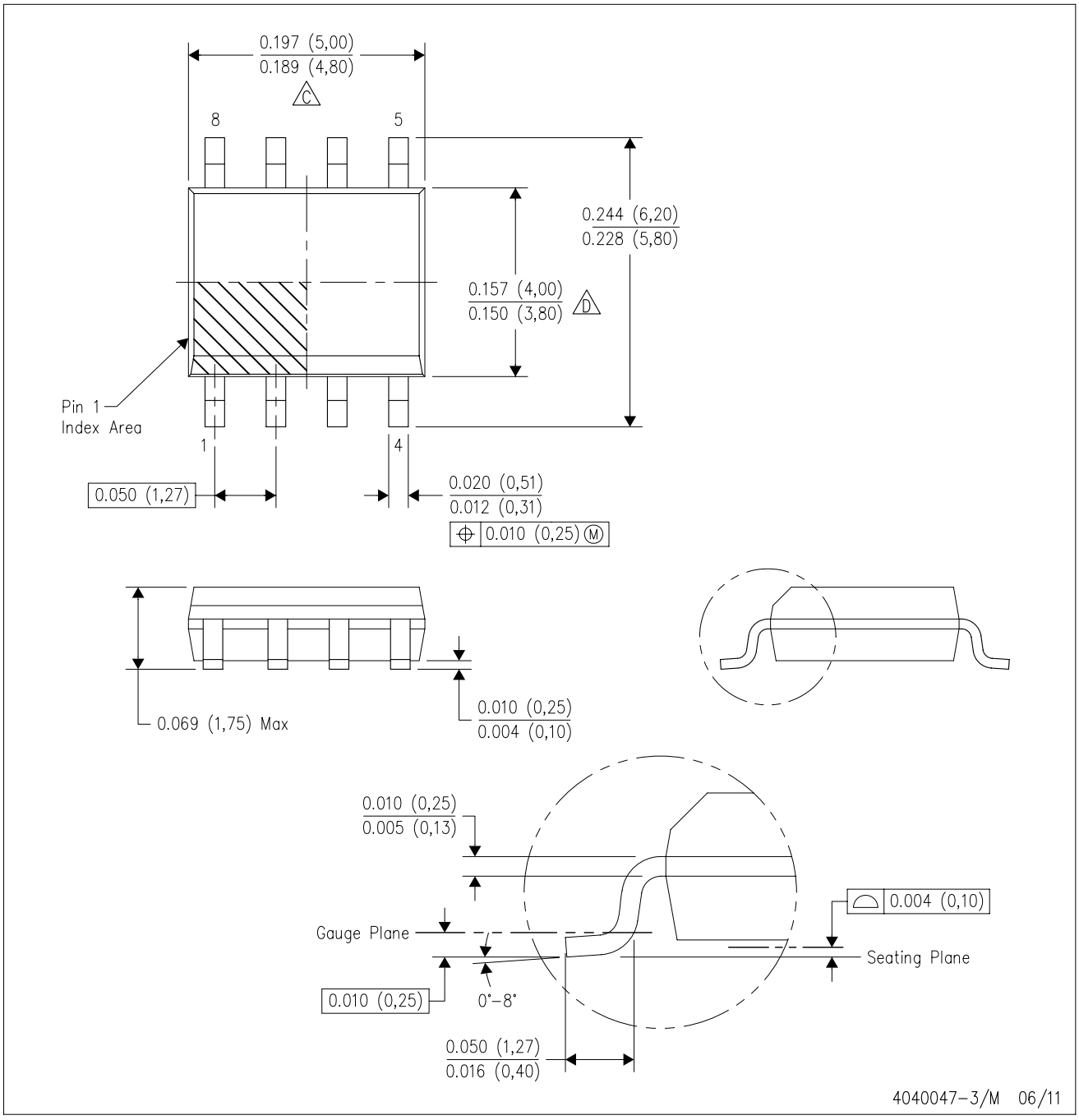
PW (R–PDSO–G14) PLASTIC SMALL OUTLINE



4040064–3/G 02/11

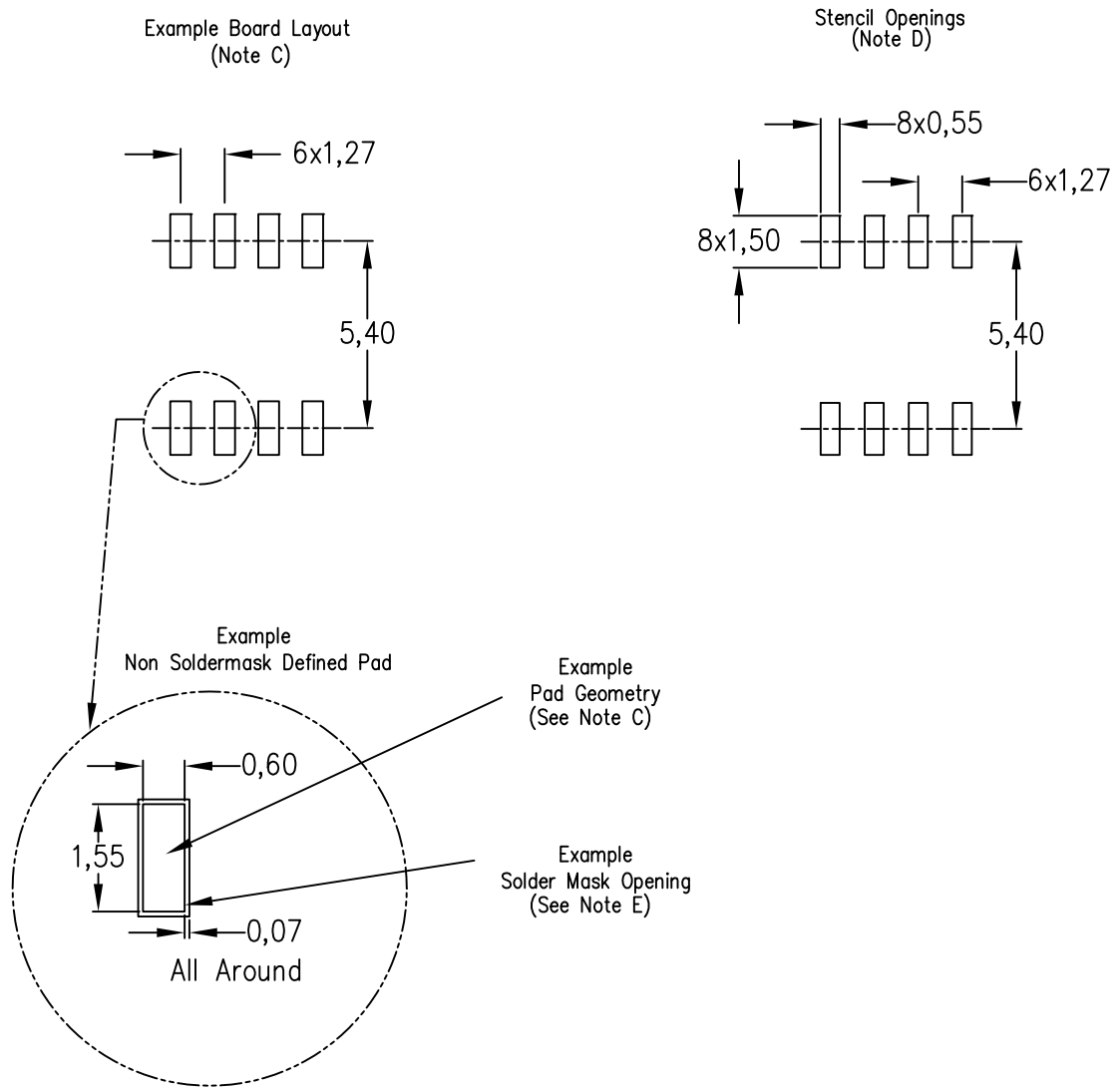
NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0,15 each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0,25 each side.
E. Falls within JEDEC MO–153

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
E. Reference JEDEC MS–012 variation AA.

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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