



# Ultralow Noise, LDO XFET® Voltage References with Current Sink and Source

## ADR440/ADR441/ADR443/ADR444/ADR445

### FEATURES

**Ultralow noise (0.1 Hz to 10 Hz)**

ADR440: 1  $\mu\text{V}$  p-p

ADR441: 1.2  $\mu\text{V}$  p-p

ADR443: 1.4  $\mu\text{V}$  p-p

ADR444: 1.8  $\mu\text{V}$  p-p

ADR445: 2.25  $\mu\text{V}$  p-p

**Superb temperature coefficient**

A Grade: 10 ppm/°C

B Grade: 3 ppm/°C

**Low dropout operation: 500 mV**

**Input range: ( $V_{\text{OUT}} + 500 \text{ mV}$ ) to 18 V**

**High output source and sink current: +10 mA and –5 mA**

**Wide temperature range: –40°C to +125°C**

### APPLICATIONS

Precision data acquisition systems

High resolution data converters

Battery-powered instrumentations

Portable medical instruments

Industrial process control systems

Precision instruments

Optical control circuits

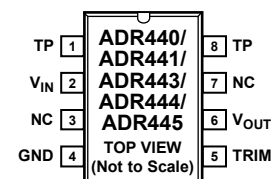
### GENERAL DESCRIPTION

The ADR44x series is a family of XFET voltage references featuring ultralow noise, high accuracy, and low temperature drift performance. Using Analog Devices, Inc., patented temperature drift curvature correction and XFET (eXtra implanted junction FET) technology, voltage change vs. temperature nonlinearity in the ADR44x is greatly minimized.

The XFET references offer better noise performance than buried Zener references, and XFET references operate off low supply voltage headroom (0.5 V). This combination of features makes the ADR44x family ideally suited for precision signal conversion applications in high-end data acquisition systems, optical networks, and medical applications.

The ADR44x family has the capability to source up to 10 mA of output current and sink up to 5 mA. It also comes with a trim terminal to adjust the output voltage over a 0.5% range without compromising performance.

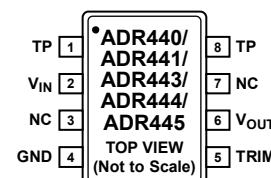
### PIN CONFIGURATIONS



#### NOTES

1. NC = NO CONNECT
2. TP = TEST PIN (DO NOT CONNECT)

Figure 1. 8-Lead SOIC\_N (R-Suffix)



#### NOTES

1. NC = NO CONNECT
2. TP = TEST PIN (DO NOT CONNECT)

Figure 2. 8-Lead MSOP (RM-Suffix)

Offered in two electrical grades, the ADR44x family is available in 8-lead MSOP and narrow SOIC packages. All versions are specified over the extended industrial temperature range of –40°C to +125°C.

Table 1. Selection Guide

| Model   | Output Voltage (V) | Initial Accuracy, $\pm$ (mV) | Temperature Coefficient (ppm/°C) |
|---------|--------------------|------------------------------|----------------------------------|
| ADR440A | 2.048              | 3                            | 10                               |
| ADR440B | 2.048              | 1                            | 3                                |
| ADR441A | 2.500              | 3                            | 10                               |
| ADR441B | 2.500              | 1                            | 3                                |
| ADR443A | 3.000              | 4                            | 10                               |
| ADR443B | 3.000              | 1.2                          | 3                                |
| ADR444A | 4.096              | 5                            | 10                               |
| ADR444B | 4.096              | 1.6                          | 3                                |
| ADR445A | 5.000              | 6                            | 10                               |
| ADR445B | 5.000              | 2                            | 3                                |

#### Rev. A

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## REVISION HISTORY

### 9/06—Rev. 0 to Rev. A

|   |           |
|---|-----------|
| Updated Format.....   | Universal |
| Changes to Features.....                                      | 1         |
| Changes to Pin Configurations.....                            | 1         |
| Changes to the Specifications Section .....                   | 3         |
| Changes to Figure 4 and Figure 5 .....                        | 9         |
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| Changes to Ordering Guide .....                               | 19        |

### 10/05—Revision 0: Initial Version

## SPECIFICATIONS

### ADR440 ELECTRICAL CHARACTERISTICS

$V_{IN} = 3\text{ V}$  to  $18\text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $C_{IN} = C_{OUT} = 0.1\text{ }\mu\text{F}$ , unless otherwise noted.

Table 2.

| Parameter                        | Symbol                       | Conditions   | Min   | Typ   | Max   | Unit                   |
|----------------------------------|------------------------------|--|-------|-------|-------|------------------------|
| OUTPUT VOLTAGE                   | $V_O$                        |  |       |       |       |                        |
| A Grade                          |                              |  | 2.045 | 2.048 | 2.051 | V                      |
| B Grade                          |                              |  | 2.047 | 2.048 | 2.049 | V                      |
| INITIAL ACCURACY                 | $V_{OERR}$                   |  |       |       |       |                        |
| A Grade                          |                              |  |       |       | 3     | mV                     |
|                                  |                              |  |       |       | 0.15  | %                      |
| B Grade                          |                              |  |       |       | 1     | mV                     |
|                                  |                              |  |       |       | 0.05  | %                      |
| TEMPERATURE DRIFT                | $TCV_O$                      |  |       |       |       |                        |
| A Grade                          |                              | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |       | 2     | 10    | ppm/ $^\circ\text{C}$  |
| B Grade                          |                              | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |       | 1     | 3     | ppm/ $^\circ\text{C}$  |
| LINE REGULATION                  | $\Delta V_O/\Delta V_{IN}$   | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   | -20   | +10   | +20   | ppm/V                  |
| LOAD REGULATION                  | $\Delta V_O/\Delta I_{LOAD}$ | $I_{LOAD} = 0\text{ mA to }10\text{ mA}$ , $V_{IN} = 3.5\text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50   |       | +50   | ppm/mA                 |
|                                  | $\Delta V_O/\Delta I_{LOAD}$ | $I_{LOAD} = 0\text{ mA to }-5\text{ mA}$ , $V_{IN} = 3.5\text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50   |       | +50   | ppm/mA                 |
| QUIESCENT CURRENT                | $I_{IN}$                     | No load, $-40^\circ\text{C} < T_A < +125^\circ\text{C}$  |       | 3     | 3.75  | mA                     |
| VOLTAGE NOISE                    | $e_N\text{ p-p}$             | 0.1 Hz to 10 Hz  |       | 1     |       | $\mu\text{V p-p}$      |
| VOLTAGE NOISE DENSITY            | $e_N$                        | 1 kHz  |       | 45    |       | nV/ $\sqrt{\text{Hz}}$ |
| TURN-ON SETTLING TIME            | $t_R$                        |  |       | 10    |       | $\mu\text{s}$          |
| LONG-TERM STABILITY <sup>1</sup> | $V_O$                        | 1000 hours   |       | 50    |       | ppm                    |
| OUTPUT VOLTAGE HYSTERESIS        | $V_{O\_HYS}$                 |  |       | 70    |       | ppm                    |
| RIPPLE REJECTION RATIO           | RRR                          | $f_{IN} = 10\text{ kHz}$   |       | -75   |       | dB                     |
| SHORT CIRCUIT TO GND             | $I_{SC}$                     |  |       | 27    |       | mA                     |
| SUPPLY VOLTAGE OPERATING RANGE   | $V_{IN}$                     |  | 3     |       | 18    | V                      |
| SUPPLY VOLTAGE HEADROOM          | $V_{IN} - V_O$               |  | 500   |       |       | mV                     |

<sup>1</sup> The long-term stability specification is noncumulative. The drift in the subsequent 1000-hour period is significantly lower than in the first 1000-hour period.

# ADR440/ADR441/ADR443/ADR444/ADR445

## ADR441 ELECTRICAL CHARACTERISTICS

$V_{IN} = 3\text{ V to }18\text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $C_{IN} = C_{OUT} = 0.1\text{ }\mu\text{F}$ , unless otherwise noted.

Table 3.

| Parameter                        | Symbol                       | Conditions   | Min   | Typ   | Max   | Unit                   |
|----------------------------------|------------------------------|--|-------|-------|-------|------------------------|
| OUTPUT VOLTAGE                   | $V_O$                        |  |       |       |       |                        |
| A Grade                          |                              |  | 2.497 | 2.500 | 2.503 | V                      |
| B Grade                          |                              |  | 2.499 | 2.500 | 2.501 | V                      |
| INITIAL ACCURACY                 | $V_{OERR}$                   |  |       |       |       |                        |
| A Grade                          |                              |  |       |       | 3     | mV                     |
|                                  |                              |  |       |       | 0.12  | %                      |
| B Grade                          |                              |  |       |       | 1     | mV                     |
|                                  |                              |  |       |       | 0.04  | %                      |
| TEMPERATURE DRIFT                | $TCV_O$                      |  |       |       |       |                        |
| A Grade                          |                              | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |       | 2     | 10    | ppm/ $^\circ\text{C}$  |
| B Grade                          |                              | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |       | 1     | 3     | ppm/ $^\circ\text{C}$  |
| LINE REGULATION                  | $\Delta V_O/\Delta V_{IN}$   | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |       | 10    | 20    | ppm/V                  |
| LOAD REGULATION                  | $\Delta V_O/\Delta I_{LOAD}$ | $I_{LOAD} = 0\text{ mA to }10\text{ mA}$ , $V_{IN} = 4\text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50   |       | +50   | ppm/mA                 |
|                                  | $\Delta V_O/\Delta I_{LOAD}$ | $I_{LOAD} = 0\text{ mA to }-5\text{ mA}$ , $V_{IN} = 4\text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50   |       | +50   | ppm/mA                 |
| QUIESCENT CURRENT                | $I_{IN}$                     | No load, $-40^\circ\text{C} < T_A < +125^\circ\text{C}$  |       | 3     | 3.75  | mA                     |
| VOLTAGE NOISE                    | $e_N\text{ p-p}$             | 0.1 Hz to 10 Hz  |       | 1.2   |       | $\mu\text{V p-p}$      |
| VOLTAGE NOISE DENSITY            | $e_N$                        | 1 kHz  |       | 48    |       | nV/ $\sqrt{\text{Hz}}$ |
| TURN-ON SETTLING TIME            | $t_R$                        |  |       | 10    |       | $\mu\text{s}$          |
| LONG-TERM STABILITY <sup>1</sup> | $V_O$                        | 1000 hours   |       | 50    |       | ppm                    |
| OUTPUT VOLTAGE HYSTERESIS        | $V_{O\_HYS}$                 |  |       | 70    |       | ppm                    |
| RIPPLE REJECTION RATIO           | RRR                          | $f_{IN} = 10\text{ kHz}$   |       | -75   |       | dB                     |
| SHORT CIRCUIT TO GND             | $I_{SC}$                     |  |       | 27    |       | mA                     |
| SUPPLY VOLTAGE OPERATING RANGE   | $V_{IN}$                     |  | 3     |       | 18    | V                      |
| SUPPLY VOLTAGE HEADROOM          | $V_{IN} - V_O$               |  | 500   |       |       | mV                     |

<sup>1</sup> The long-term stability specification is noncumulative. The drift in subsequent 1000-hour period is significantly lower than in the first 1000-hour period.

## ADR443 ELECTRICAL CHARACTERISTICS

$V_{IN} = 3.5 \text{ V to } 18 \text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $C_{IN} = C_{OUT} = 0.1 \mu\text{F}$ , unless otherwise noted.

Table 4.

| Parameter                        | Symbol                         | Conditions   | Min    | Typ   | Max    | Unit                   |
|----------------------------------|--------------------------------|--|--------|-------|--------|------------------------|
| OUTPUT VOLTAGE                   | $V_O$                          |  |        |       |        |                        |
| A Grade                          |                                |  | 2.996  | 3.000 | 3.004  | V                      |
| B Grade                          |                                |  | 2.9988 | 3.000 | 3.0012 | V                      |
| INITIAL ACCURACY                 | $V_{OERR}$                     |  |        |       |        |                        |
| A Grade                          |                                |  |        |       | 4      | mV                     |
|                                  |                                |  |        |       | 0.13   | %                      |
| B Grade                          |                                |  |        |       | 1.2    | mV                     |
|                                  |                                |  |        |       | 0.04   | %                      |
| TEMPERATURE DRIFT                | $TCV_O$                        |  |        |       |        |                        |
| A Grade                          |                                | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |        | 2     | 10     | ppm/ $^\circ\text{C}$  |
| B Grade                          |                                | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |        | 1     | 3      | ppm/ $^\circ\text{C}$  |
| LINE REGULATION                  | $\Delta V_O / \Delta V_{IN}$   | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |        | 10    | 20     | ppm/V                  |
| LOAD REGULATION                  | $\Delta V_O / \Delta I_{LOAD}$ | $I_{LOAD} = 0 \text{ mA to } 10 \text{ mA}$ , $V_{IN} = 5 \text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50    |       | +50    | ppm/mA                 |
|                                  | $\Delta V_O / \Delta I_{LOAD}$ | $I_{LOAD} = 0 \text{ mA to } -5 \text{ mA}$ , $V_{IN} = 5 \text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50    |       | +50    | ppm/mA                 |
| QUIESCENT CURRENT                | $I_{IN}$                       | No load, $-40^\circ\text{C} < T_A < +125^\circ\text{C}$  |        | 3     | 3.75   | mA                     |
| VOLTAGE NOISE                    | $e_N \text{ p-p}$              | 0.1 Hz to 10 Hz  |        | 1.4   |        | $\mu\text{V p-p}$      |
| VOLTAGE NOISE DENSITY            | $e_N$                          | 1 kHz  |        | 57.6  |        | nV/ $\sqrt{\text{Hz}}$ |
| TURN-ON SETTLING TIME            | $t_R$                          |  |        | 10    |        | $\mu\text{s}$          |
| LONG-TERM STABILITY <sup>1</sup> | $V_O$                          | 1000 hours   |        | 50    |        | ppm                    |
| OUTPUT VOLTAGE HYSTERESIS        | $V_{O\_HYS}$                   |  |        | 70    |        | ppm                    |
| RIPPLE REJECTION RATIO           | RRR                            | $f_{IN} = 10 \text{ kHz}$  |        | -75   |        | dB                     |
| SHORT CIRCUIT TO GND             | $I_{SC}$                       |  |        | 27    |        | mA                     |
| SUPPLY VOLTAGE OPERATING RANGE   | $V_{IN}$                       |  | 3.5    |       | 18     | V                      |
| SUPPLY VOLTAGE HEADROOM          | $V_{IN} - V_O$                 |  | 500    |       |        | mV                     |

<sup>1</sup> The long-term stability specification is noncumulative. The drift in the subsequent 1000-hour period is significantly lower than in the first 1000-hour period.

# ADR440/ADR441/ADR443/ADR444/ADR445

## ADR444 ELECTRICAL CHARACTERISTICS

$V_{IN} = 4.6 \text{ V to } 18 \text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $C_{IN} = C_{OUT} = 0.1 \mu\text{F}$ , unless otherwise noted.

Table 5.

| Parameter                        | Symbol                         | Conditions   | Min    | Typ   | Max    | Unit                   |
|----------------------------------|--------------------------------|--|--------|-------|--------|------------------------|
| OUTPUT VOLTAGE                   | $V_O$                          |  |        |       |        |                        |
| A Grade                          |                                |  | 4.091  | 4.096 | 4.101  | V                      |
| B Grade                          |                                |  | 4.0944 | 4.096 | 4.0976 | V                      |
| INITIAL ACCURACY                 | $V_{OERR}$                     |  |        |       |        |                        |
| A Grade                          |                                |  |        |       | 5      | mV                     |
|                                  |                                |  |        |       | 0.13   | %                      |
| B Grade                          |                                |  |        |       | 1.6    | mV                     |
|                                  |                                |  |        |       | 0.04   | %                      |
| TEMPERATURE DRIFT                | $TCV_O$                        |  |        |       |        |                        |
| A Grade                          |                                | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |        | 2     | 10     | ppm/ $^\circ\text{C}$  |
| B Grade                          |                                | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |        | 1     | 3      | ppm/ $^\circ\text{C}$  |
| LINE REGULATION                  | $\Delta V_O / \Delta V_{IN}$   | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |        | 10    | 20     | ppm/V                  |
| LOAD REGULATION                  | $\Delta V_O / \Delta I_{LOAD}$ | $I_{LOAD} = 0 \text{ mA to } 10 \text{ mA}$ , $V_{IN} = 5.5 \text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50    |       | +50    | ppm/mA                 |
|                                  | $\Delta V_O / \Delta I_{LOAD}$ | $I_{LOAD} = 0 \text{ mA to } -5 \text{ mA}$ , $V_{IN} = 5.5 \text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50    |       | +50    | ppm/mA                 |
| QUIESCENT CURRENT                | $I_{IN}$                       | No load, $-40^\circ\text{C} < T_A < +125^\circ\text{C}$  |        | 3     | 3.75   | mA                     |
| VOLTAGE NOISE                    | $e_N \text{ p-p}$              | 0.1 Hz to 10 Hz  |        | 1.8   |        | $\mu\text{V p-p}$      |
| VOLTAGE NOISE DENSITY            | $e_N$                          | 1 kHz  |        | 78.6  |        | nV/ $\sqrt{\text{Hz}}$ |
| TURN-ON SETTLING TIME            | $t_R$                          |  |        | 10    |        | $\mu\text{s}$          |
| LONG-TERM STABILITY <sup>1</sup> | $V_O$                          | 1000 hours   |        | 50    |        | ppm                    |
| OUTPUT VOLTAGE HYSTERESIS        | $V_{O\_HYS}$                   |  |        | 70    |        | ppm                    |
| RIPPLE REJECTION RATIO           | RRR                            | $f_{IN} = 10 \text{ kHz}$  |        | -75   |        | dB                     |
| SHORT CIRCUIT TO GND             | $I_{SC}$                       |  |        | 27    |        | mA                     |
| SUPPLY VOLTAGE OPERATING RANGE   | $V_{IN}$                       |  | 4.6    |       | 18     | V                      |
| SUPPLY VOLTAGE HEADROOM          | $V_{IN} - V_O$                 |  | 500    |       |        | mV                     |

<sup>1</sup> The long-term stability specification is noncumulative. The drift in the subsequent 1000-hour period is significantly lower than in the first 1000-hour period.

## ADR445 ELECTRICAL CHARACTERISTICS

$V_{IN} = 5.5 \text{ V to } 18 \text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $C_{IN} = C_{OUT} = 0.1 \mu\text{F}$ , unless otherwise noted.

Table 6.

| Parameter                        | Symbol                         | Conditions   | Min   | Typ   | Max   | Unit                   |
|----------------------------------|--------------------------------|--|-------|-------|-------|------------------------|
| OUTPUT VOLTAGE                   | $V_O$                          |  |       |       |       |                        |
| A Grade                          |                                |  | 4.994 | 5.000 | 5.006 | V                      |
| B Grade                          |                                |  | 4.998 | 5.000 | 5.002 | V                      |
| INITIAL ACCURACY                 | $V_{OERR}$                     |  |       |       |       |                        |
| A Grade                          |                                |  |       |       | 6     | mV                     |
|                                  |                                |  |       |       | 0.12  | %                      |
| B Grade                          |                                |  |       |       | 2     | mV                     |
|                                  |                                |  |       |       | 0.04  | %                      |
| TEMPERATURE DRIFT                | $TCV_O$                        |  |       |       |       |                        |
| A Grade                          |                                | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |       | 2     | 10    | ppm/ $^\circ\text{C}$  |
| B Grade                          |                                | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |       | 1     | 3     | ppm/ $^\circ\text{C}$  |
| LINE REGULATION                  | $\Delta V_O / \Delta V_{IN}$   | $-40^\circ\text{C} < T_A < +125^\circ\text{C}$   |       | 10    | 20    | ppm/V                  |
| LOAD REGULATION                  | $\Delta V_O / \Delta I_{LOAD}$ | $I_{LOAD} = 0 \text{ mA to } 10 \text{ mA}$ , $V_{IN} = 6.5 \text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50   |       | +50   | ppm/mA                 |
|                                  | $\Delta V_O / \Delta I_{LOAD}$ | $I_{LOAD} = 0 \text{ mA to } -5 \text{ mA}$ , $V_{IN} = 6.5 \text{ V}$ ,<br>$-40^\circ\text{C} < T_A < +125^\circ\text{C}$ | -50   |       | +50   | ppm/mA                 |
| QUIESCENT CURRENT                | $I_{IN}$                       | No load, $-40^\circ\text{C} < T_A < +125^\circ\text{C}$  |       | 3     | 3.75  | mA                     |
| VOLTAGE NOISE                    | $e_N \text{ p-p}$              | 0.1 Hz to 10 Hz  |       | 2.25  |       | $\mu\text{V p-p}$      |
| VOLTAGE NOISE DENSITY            | $e_N$                          | 1 kHz  |       | 90    |       | nV/ $\sqrt{\text{Hz}}$ |
| TURN-ON SETTLING TIME            | $t_R$                          |  |       | 10    |       | $\mu\text{s}$          |
| LONG-TERM STABILITY <sup>1</sup> | $V_O$                          | 1000 hours   |       | 50    |       | ppm                    |
| OUTPUT VOLTAGE HYSTERESIS        | $V_{O\_HYS}$                   |  |       | 70    |       | ppm                    |
| RIPPLE REJECTION RATIO           | RRR                            | $f_{IN} = 10 \text{ kHz}$  |       | -75   |       | dB                     |
| SHORT CIRCUIT TO GND             | $I_{SC}$                       |  |       | 27    |       | mA                     |
| SUPPLY VOLTAGE OPERATING RANGE   | $V_{IN}$                       |  | 5.5   |       | 18    | V                      |
| SUPPLY VOLTAGE HEADROOM          | $V_{IN} - V_O$                 |  | 500   |       |       | mV                     |

<sup>1</sup> The long-term stability specification is noncumulative. The drift in the subsequent 1000-hour period is significantly lower than in the first 1000-hour period.

## ABSOLUTE MAXIMUM RATINGS

$T_A = 25^\circ\text{C}$ , unless otherwise noted.

Table 7.

| Parameter                            | Rating                                      |
|--------------------------------------|---|
| Supply Voltage                       | 20 V  |
| Output Short-Circuit Duration to GND | Indefinite                                  |
| Storage Temperature Range            | $-65^\circ\text{C}$ to $+125^\circ\text{C}$ |
| Operating Temperature Range          | $-40^\circ\text{C}$ to $+125^\circ\text{C}$ |
| Junction Temperature Range           | $-65^\circ\text{C}$ to $+150^\circ\text{C}$ |
| Lead Temperature, Soldering (60 sec) | $300^\circ\text{C}$                         |

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## THERMAL RESISTANCE

$\theta_{JA}$  is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 8. Thermal Resistance

| Package Type             | $\theta_{JA}$ | $\theta_{JC}$ | Unit                      |
|--------------------------|---------------|---------------|---------------------------|
| 8-Lead SOIC_N (R-Suffix) | 130           | 43            | $^\circ\text{C}/\text{W}$ |
| 8-Lead MSOP (RM-Suffix)  | 190           |               | $^\circ\text{C}/\text{W}$ |

## ESD CAUTION



**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.



## TYPICAL PERFORMANCE CHARACTERISTICS

$V_{IN} = 7\text{ V}$ ,  $T_A = 25^\circ\text{C}$ ,  $C_{IN} = C_{OUT} = 0.1\text{ }\mu\text{F}$ , unless otherwise noted.

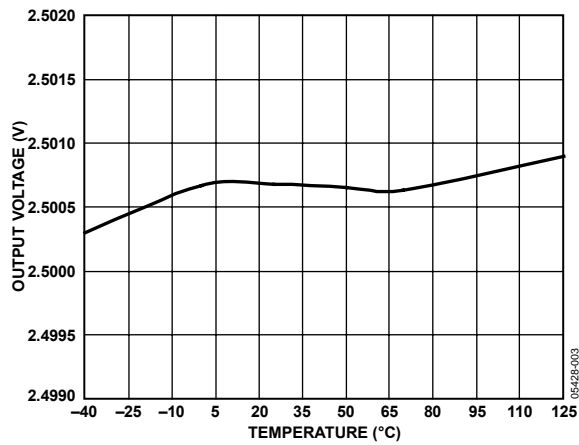


Figure 3. ADR441 Output Voltage vs. Temperature

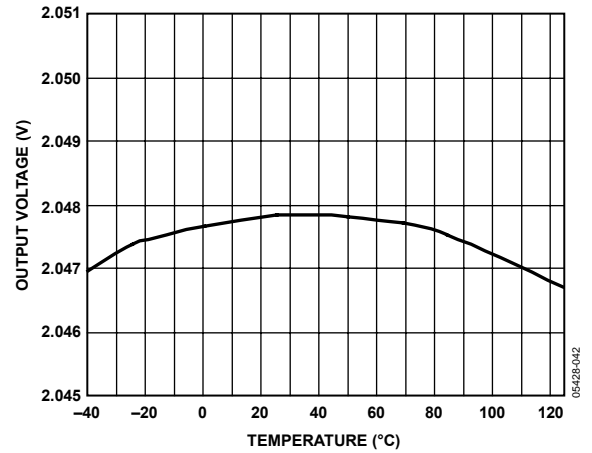


Figure 6. ADR440 Output Voltage vs. Temperature

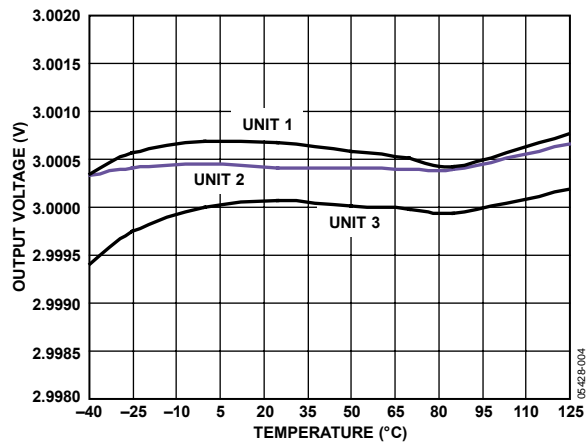


Figure 4. ADR443 Output Voltage vs. Temperature

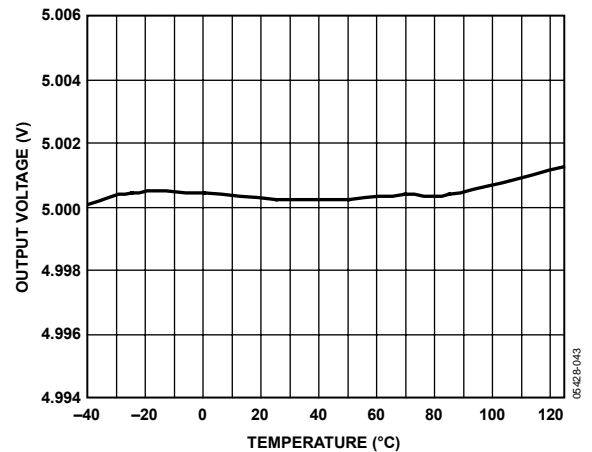


Figure 7. ADR445 Output Voltage vs. Temperature

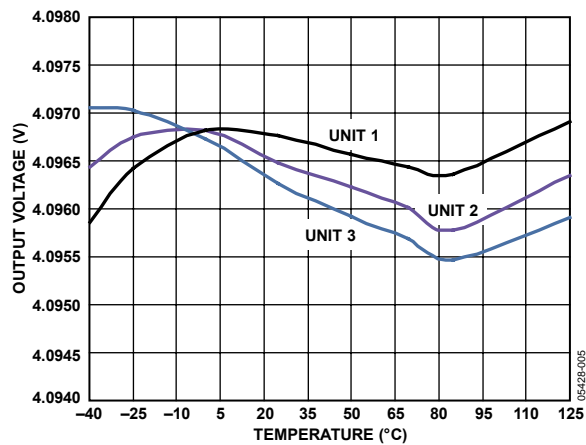


Figure 5. ADR444 Output Voltage vs. Temperature

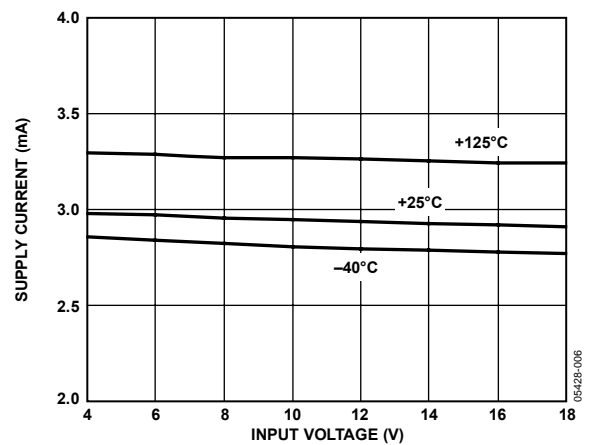


Figure 8. ADR441 Supply Current vs. Input Voltage

# ADR440/ADR441/ADR443/ADR444/ADR445

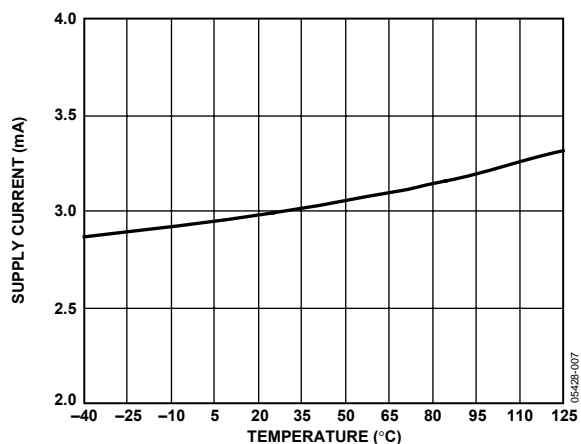


Figure 9. ADR441 Supply Current vs. Temperature

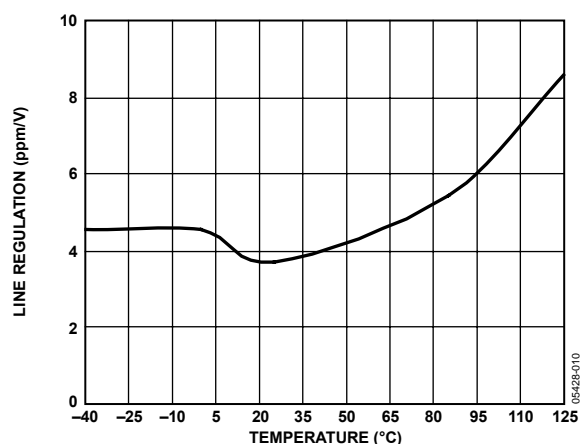


Figure 12. ADR441 Line Regulation vs. Temperature

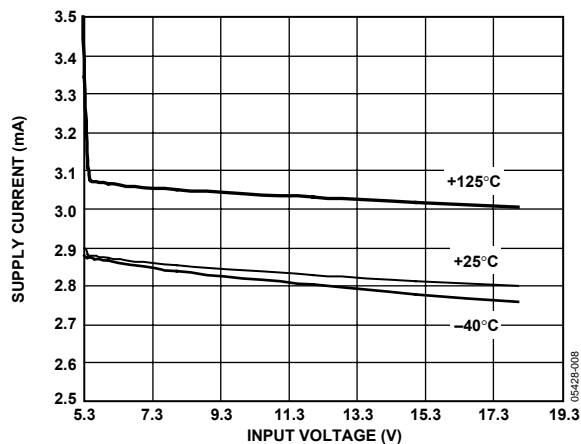


Figure 10. ADR445 Supply Current vs. Input Voltage

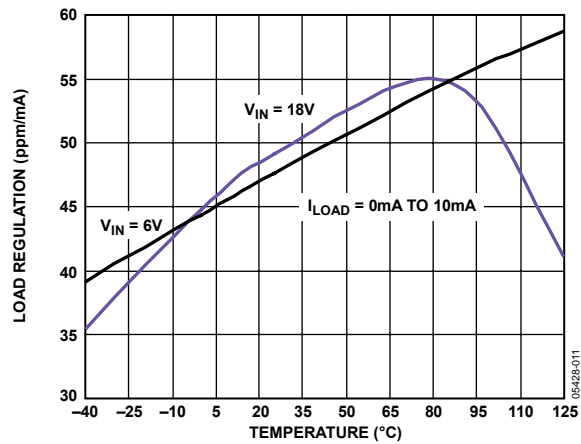


Figure 13. ADR441 Load Regulation vs. Temperature

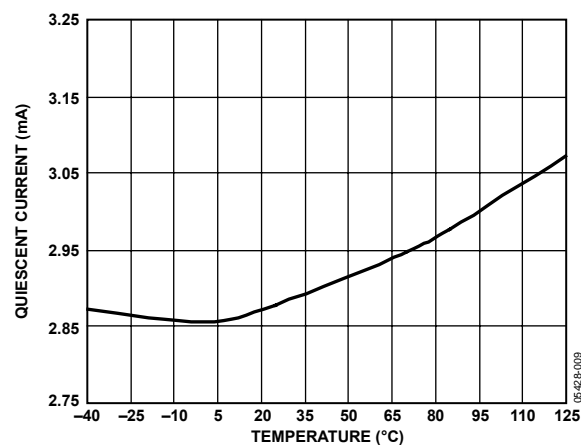


Figure 11. ADR445 Quiescent Current vs. Temperature

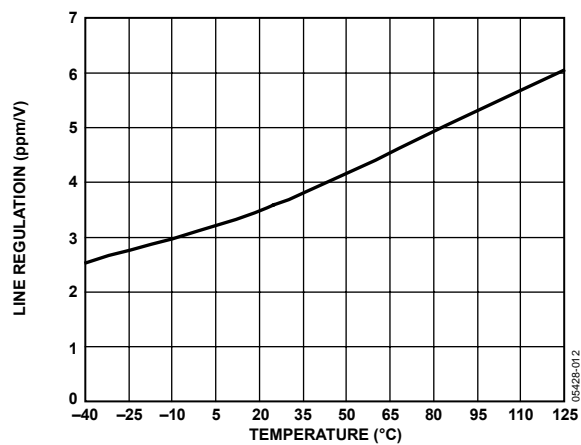


Figure 14. ADR445 Line Regulation vs. Temperature

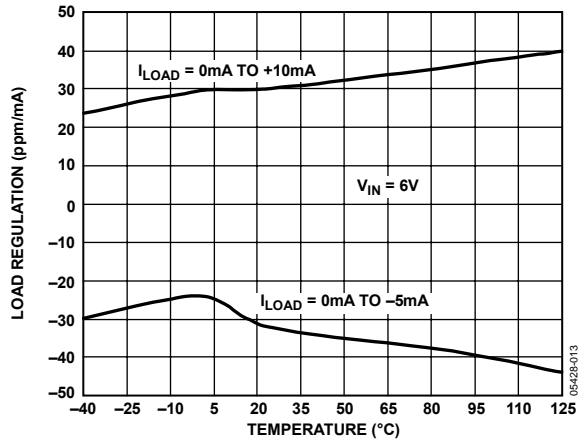


Figure 15. ADR445 Load Regulation vs. Temperature

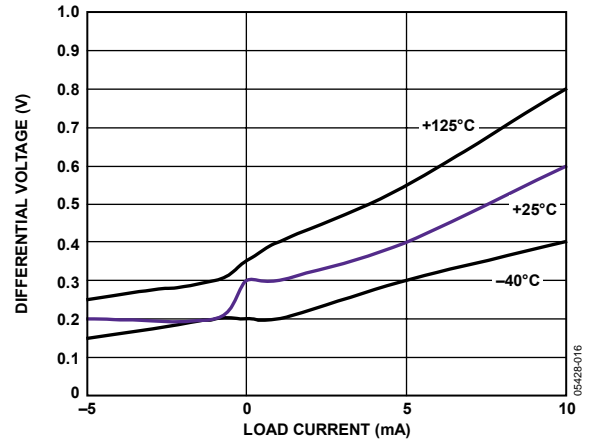


Figure 18. ADR445 Minimum Input/Output Differential Voltage vs. Load Current

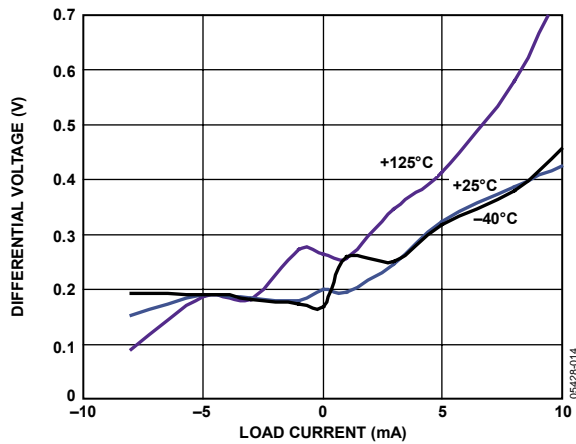


Figure 16. ADR441 Minimum Input/Output Differential Voltage vs. Load Current

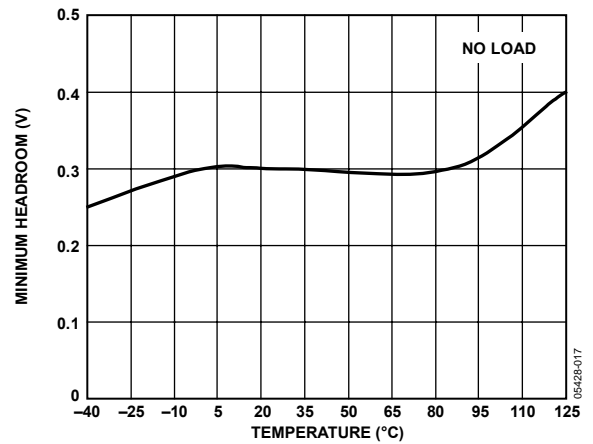


Figure 19. ADR445 Minimum Headroom vs. Temperature

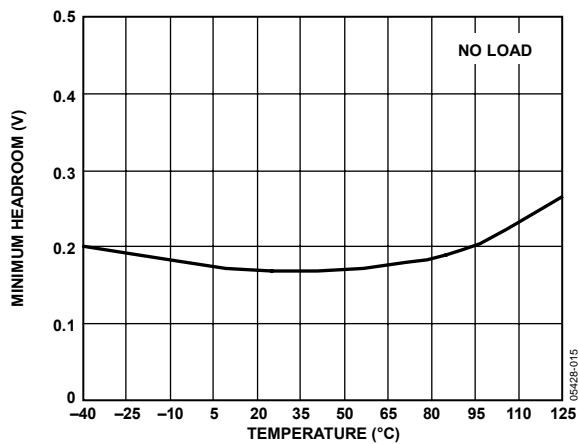


Figure 17. ADR441 Minimum Headroom vs. Temperature

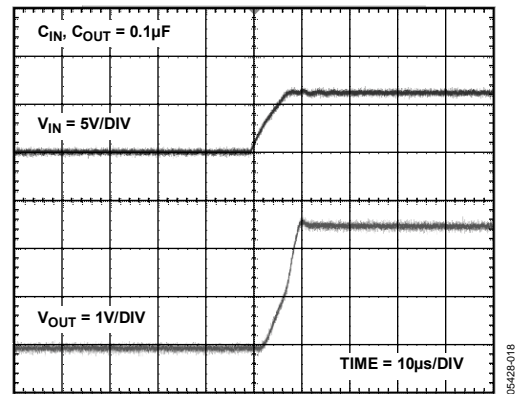


Figure 20. ADR441 Turn-On Response

# ADR440/ADR441/ADR443/ADR444/ADR445

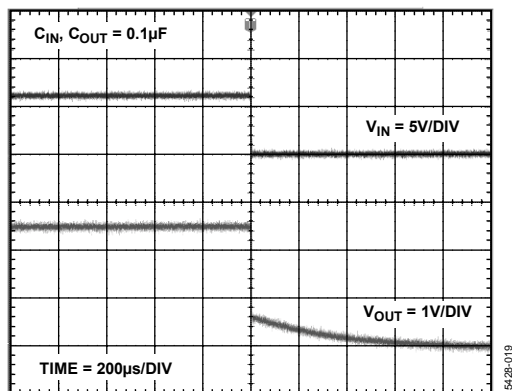


Figure 21. ADR441 Turn-Off Response

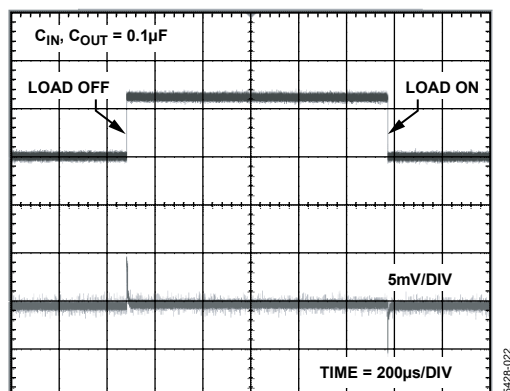


Figure 24. ADR441 Load Transient Response

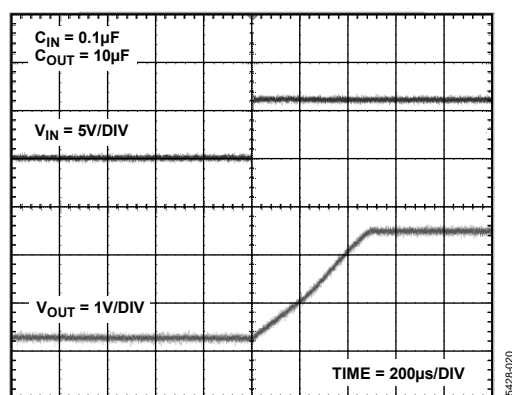


Figure 22. ADR441 Turn-On Response

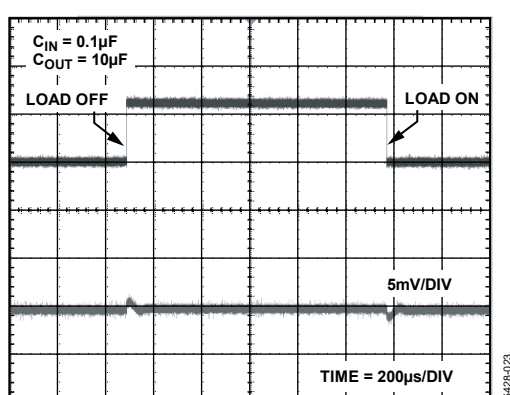


Figure 25. ADR441 Load Transient Response

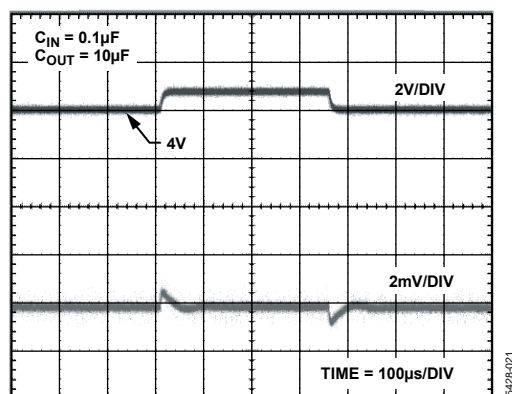


Figure 23. ADR441 Line Transient Response

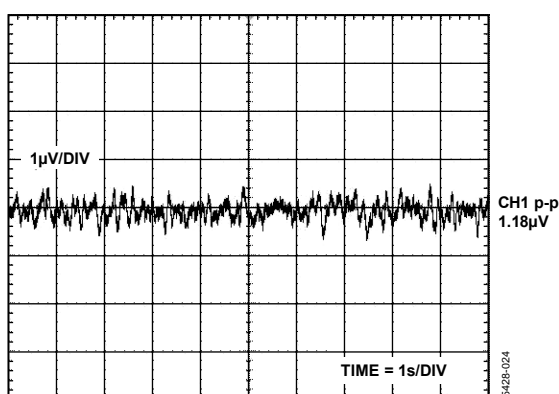


Figure 26. ADR441 0.1 Hz to 10.0 Hz Voltage Noise

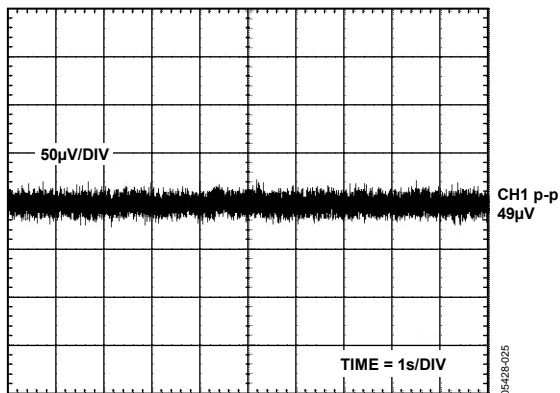


Figure 27. ADR441 10 Hz to 10 kHz Voltage Noise

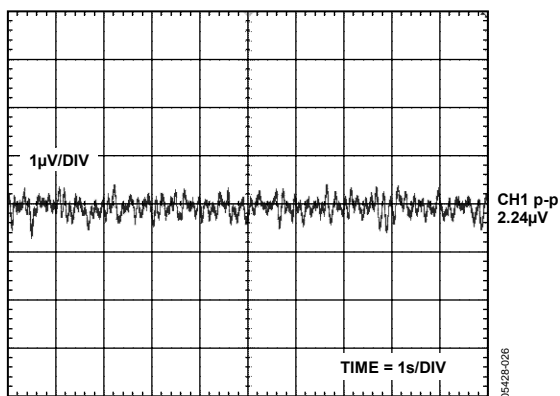


Figure 28. ADR445 0.1 Hz to 10.0 Hz Voltage Noise

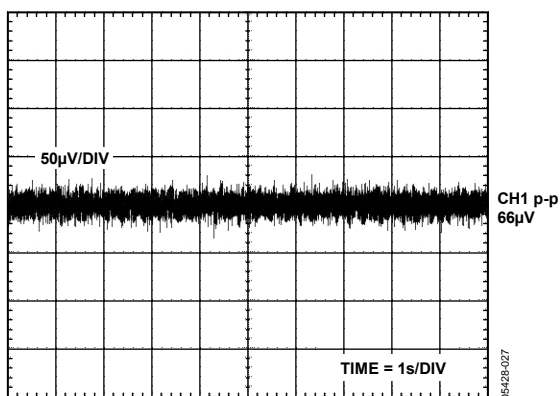


Figure 29. ADR445 10 Hz to 10 kHz Voltage Noise

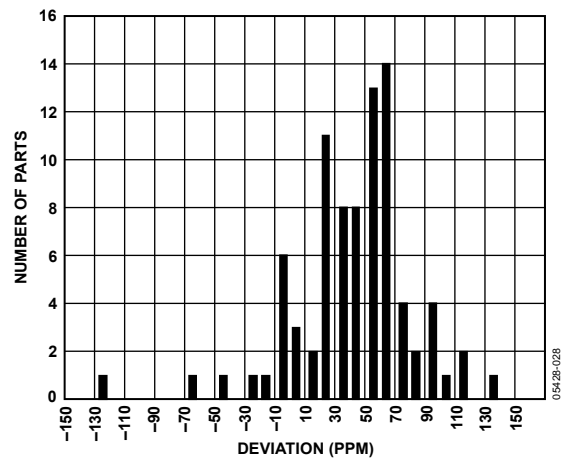


Figure 30. ADR441 Typical Output Voltage Hysteresis

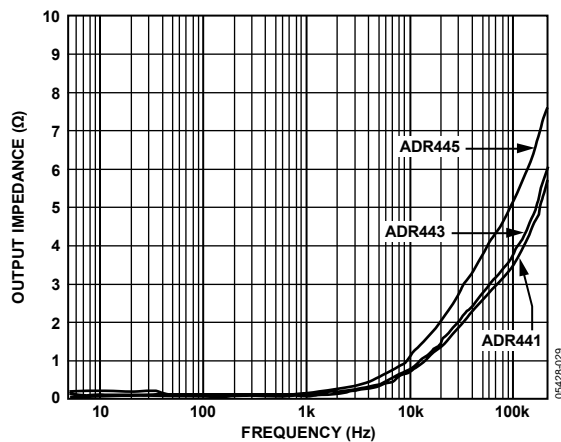


Figure 31. Output Impedance vs. Frequency

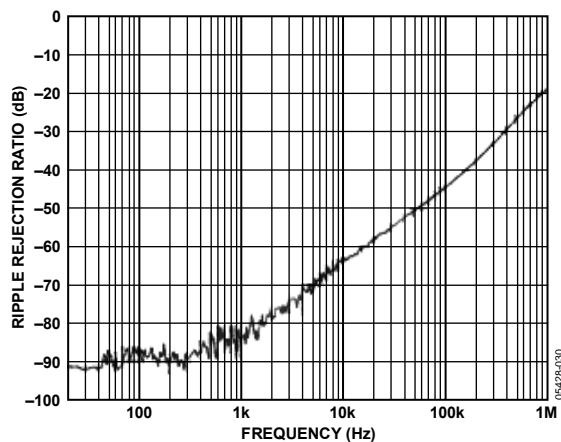


Figure 32. Ripple Rejection Ratio vs. Frequency

## THEORY OF OPERATION

The ADR44x series of references uses a new reference generation technique known as XFET (eXtra implanted junction FET). This technique yields a reference with low dropout, good thermal hysteresis, and exceptionally low noise. The core of the XFET reference consists of two junction field-effect transistors (JFETs), one of which has an extra channel implant to raise its pinch-off voltage. By running the two JFETs at the same drain current, the difference in pinch-off voltage can be amplified and used to form a highly stable voltage reference.

The intrinsic reference voltage is around 0.5 V with a negative temperature coefficient of about  $-120 \text{ ppm}/^\circ\text{C}$ . This slope is essentially constant to the dielectric constant of silicon, and it can be closely compensated for by adding a correction term generated in the same fashion as the proportional-to-temperature (PTAT) term used to compensate band gap references. The advantage of an XFET reference is its correction term, which is approximately 20 times lower and requires less correction than that of a band gap reference. Because most of the noise of a band gap reference comes from the temperature compensation circuitry, the XFET results in much lower noise.

Figure 33 shows the basic topology of the ADR44x series. The temperature correction term is provided by a current source with a value designed to be proportional to absolute temperature. The general equation is

$$V_{OUT} = G (\Delta V_P - R1 \times I_{PTAT}) \quad (1)$$

where:

$G$  is the gain of the reciprocal of the divider ratio.

$\Delta V_P$  is the difference in pinch-off voltage between the two JFETs.

$I_{PTAT}$  is the positive temperature coefficient correction current.

ADR44x devices are created by on-chip adjustment of  $R2$  and  $R3$  to achieve the different voltage option at the reference output.

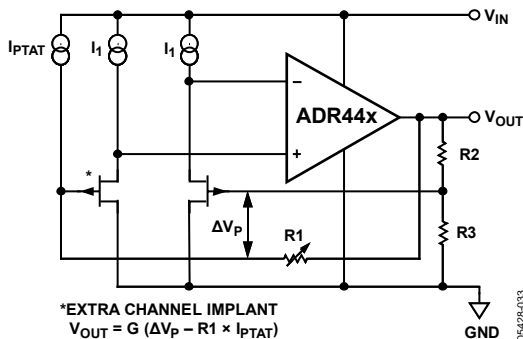


Figure 33. Simplified Schematic Device

## POWER DISSIPATION CONSIDERATIONS

The ADR44x family of references is guaranteed to deliver load currents to 10 mA with an input voltage that ranges from 3 V to 18 V. When these devices are used in applications at higher currents, users should use the following equation to account for the temperature effects of increases in power dissipation:

$$T_J = P_D \times \theta_{JA} + T_A \quad (2)$$

where:

$T_J$  and  $T_A$  are the junction and ambient temperatures, respectively.

$P_D$  is the device power dissipation.

$\theta_{JA}$  is the device package thermal resistance.

## BASIC VOLTAGE REFERENCE CONNECTIONS

The ADR44x family requires a  $0.1 \mu\text{F}$  capacitor on the input and the output for stability. While not required for operation, a  $10 \mu\text{F}$  capacitor at the input can help with line voltage transient performance.

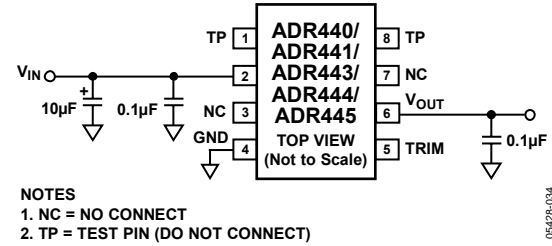


Figure 34. Basic Voltage Reference Configuration

## NOISE PERFORMANCE

The noise generated by the ADR44x family of references is typically less than  $1.4 \mu\text{V p-p}$  over the 0.1 Hz to 10.0 Hz band for ADR440, ADR441, and ADR443. Figure 26 shows the 0.1 Hz to 10 Hz noise of the ADR441, which is only  $1.2 \mu\text{V p-p}$ . The noise measurement is made with a band-pass filter made of a 2-pole high-pass filter with a corner frequency at 0.1 Hz and a 2-pole low-pass filter with a corner frequency at 10.0 Hz.

## TURN-ON TIME

Upon application of power (cold start), the time required for the output voltage to reach its final value within a specified error band is defined as the *turn-on settling time*. Two components normally associated with this are the time for the active circuits to settle and the time for the thermal gradients on the chip to stabilize. Figure 20 and Figure 21 show the turn-on and turn-off settling times for the ADR441.

## APPLICATIONS

### OUTPUT ADJUSTMENT

The ADR44x family features a TRIM pin that allows the user to adjust the output voltage of the part over a limited range. This allows errors from the reference and overall system errors to be trimmed out by connecting a potentiometer between the output and the ground, with the wiper connected to the TRIM pin. Figure 35 shows the optimal trim configuration. R1 allows fine adjustment of the output and is not always required. R<sub>P</sub> should be sufficiently large so that the maximum output current from the ADR44x is not exceeded.

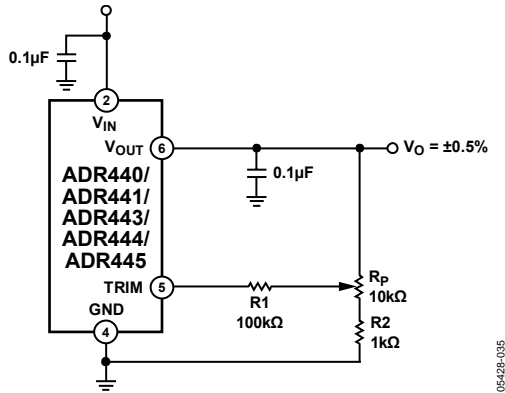


Figure 35. ADR44x Trim Function

Using the trim function has a negligible effect on the temperature performance of the ADR44x. However, all resistors need to be low temperature coefficient resistors, or errors can occur.

### BIPOLAR OUTPUTS

By connecting the output of the ADR44x to the inverting terminal of an operational amplifier, it is possible to obtain both positive and negative reference voltages. Care must be taken when choosing Resistor R1 and Resistor R2 (see Figure 36). They must be matched as closely as possible to ensure minimal differences between the negative and positive outputs. In addition, care must be taken to ensure performance over temperature. Use low temperature coefficient resistors if the circuit is used over temperature; otherwise, differences exist between the two outputs.

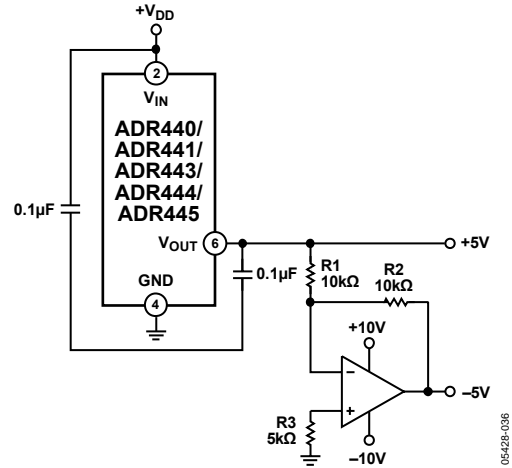


Figure 36. ADR44x Bipolar Outputs

### NEGATIVE REFERENCE

Figure 37 shows how to connect the ADR44x and a standard operational amplifier, such as the OP1177, to provide negative voltage. This configuration provides two main advantages. First, it only requires two devices; therefore, it does not require excessive board space. Second, and more importantly, it does not require any external resistors. This means the performance of this circuit does not rely on choosing low temperature coefficient resistors to ensure accuracy.

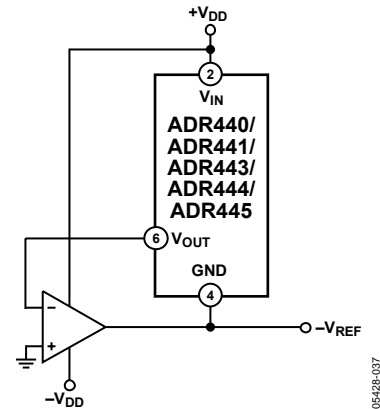


Figure 37. ADR44x Negative Reference

V<sub>OUT</sub> is at virtual ground, and the negative reference is taken directly from the output of the operational amplifier. If the negative supply voltage is close to the reference output, the operational amplifier must be dual supply and have low offset and rail-to-rail capability.

# ADR440/ADR441/ADR443/ADR444/ADR445

## PROGRAMMABLE VOLTAGE SOURCE

To obtain different voltages than those offered by the ADR44x, some extra components are needed. In Figure 38, two potentiometers are used to set the desired voltage, while the buffering amplifier provides current drive. The potentiometer connected between  $V_{OUT}$  and GND, with its wiper connected to the noninverting input of the operational amplifier, takes care of coarse trim. The second potentiometer, with its wiper connected to the trim terminal of the ADR44x, is used for fine adjustment. Resolution depends on the end-to-end resistance value and the resolution of the selected potentiometer.

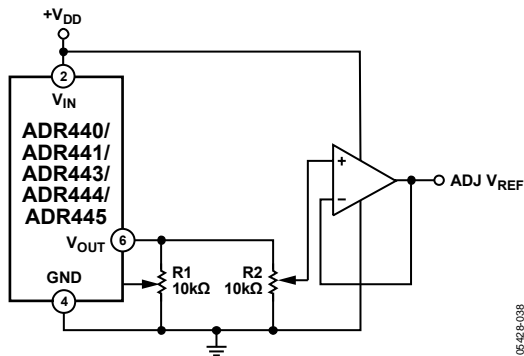


Figure 38. Programmable Voltage Source

For a completely programmable solution, replace the two potentiometers in Figure 38 with one Analog Devices dual digital potentiometer, offered with either an SPI® or an I²C® interface. These interfaces set the position of the wiper on both potentiometers and allow the output voltage to be set. Table 9 lists compatible Analog Devices digital potentiometers.

Table 9. Digital Potentiometer Parts

| Part No. | No. of Channels | No. of Positions | ITF | R (kΩ)         | V <sub>DD</sub> <sup>1</sup> |
|----------|-----------------|------------------|-----|----------------|------------------------------|
| AD5251   | 2.00            | 64.00            | I²C | 1, 10, 50, 100 | 5.5                          |
| AD5207   | 2.00            | 256.00           | SPI | 10, 50, 100    | 5.5                          |
| AD5242   | 2.00            | 256.00           | I²C | 10, 100, 1M    | 5.5                          |
| AD5262   | 2.00            | 256.00           | SPI | 20, 50, 200    | 15                           |
| AD5282   | 2.00            | 256.00           | I²C | 20, 50, 100    | 15                           |
| AD5252   | 2.00            | 256.00           | I²C | 1, 10, 50, 100 | 5.5                          |
| AD5232   | 2.00            | 256.00           | SPI | 10, 50, 100    | 5.5                          |
| AD5235   | 2.00            | 1024.00          | SPI | 25, 250        | 5.5                          |
| ADN2850  | 2.00            | 1024.00          | SPI | 25, 250        | 5.5                          |

<sup>1</sup> Can also use a negative supply.

Adding a negative supply to the operational amplifier allows the user also to produce a negative programmable reference, by connecting the reference output to the inverting terminal of the operational amplifier. Choose feedback resistors to minimize errors over temperature.

## PROGRAMMABLE CURRENT SOURCE

It is possible to build a programmable current source using a setup similar to the programmable voltage source, as shown in Figure 39. The constant voltage on the gate of the transistor sets the current through the load. Varying the voltage on the gate changes the current. This circuit does not require a dual digital potentiometer.

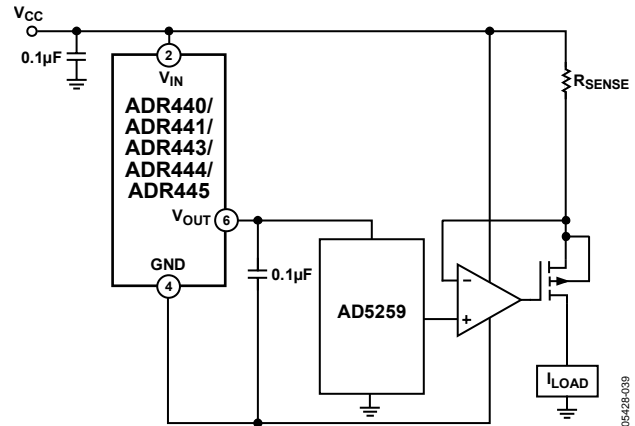


Figure 39. Programmable Current Source

## HIGH VOLTAGE FLOATING CURRENT SOURCE

Use the circuit in Figure 40 to generate a floating current source with minimal self heating. This particular configuration can operate on high supply voltages, determined by the breakdown voltage of the N-channel JFET.

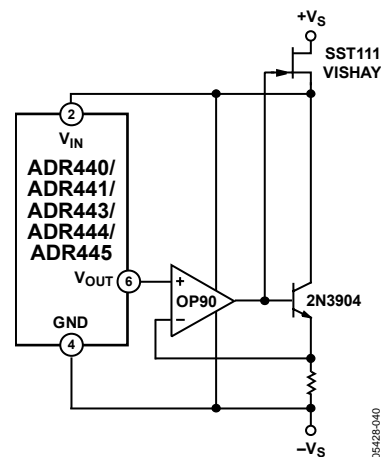


Figure 40. Floating Current Source



## PRECISION OUTPUT REGULATOR (BOOSTED REFERENCE)

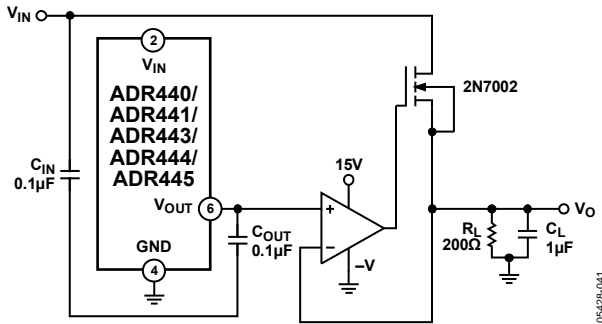
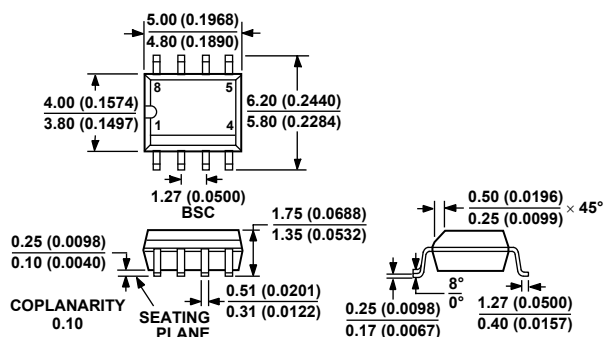


Figure 41. Boosted Output Reference

Higher current drive capability can be obtained, without sacrificing accuracy, by using the circuit in Figure 41. The operational amplifier regulates the MOSFET turn-on, forcing  $V_O$  to equal the  $V_{REF}$ . Current is then drawn from  $V_{IN}$ , allowing increased current drive capability. The circuit allows a 50 mA load; if higher current drive is required, use a larger MOSFET. For fast transient response, add a buffer at  $V_O$  to aid with capacitive loading.

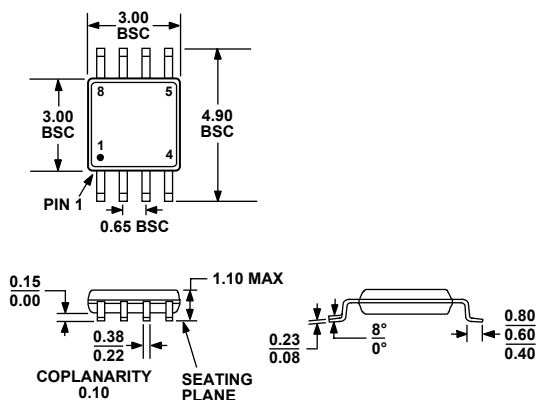
## OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MS-012-AA  
CONTROLLING DIMENSIONS ARE IN MILLIMETERS; INCH DIMENSIONS  
(IN PARENTHESES) ARE ROUNDED-OFF MILLIMETER EQUIVALENTS FOR  
REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN

Figure 42. 8-Lead Standard Small Outline Package [SOIC\_N]  
Narrow Body  
(R-8)

Dimensions shown in millimeters and (inches)



COMPLIANT TO JEDEC STANDARDS MO-187-AA

Figure 43. 8-Lead Mini Small Outline Package [MSOP]  
(RM-8)

Dimensions show in millimeters

# ADR440/ADR441/ADR443/ADR444/ADR445

## ORDERING GUIDE

| Model                         | Output Voltage (V) | Initial Accuracy, $\pm$ |      | Temperature Coefficient Package (ppm/°C) | Package Description | Branding | Temperature Range | Package Option |
|-------------------------------|--------------------|-------------------------|------|--|---------------------|----------|-------------------|----------------|
| ADR440ARZ <sup>1</sup>        | 2.048              | 3                       | 0.15 | 10                                       | 8-Lead SOIC_N       | R01      | –40°C to +125°C   | R-8            |
| ADR440ARZ-REEL7 <sup>1</sup>  | 2.048              | 3                       | 0.15 | 10                                       | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR440ARMZ <sup>1</sup>       | 2.048              | 3                       | 0.15 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR440ARMZ-REEL7 <sup>1</sup> | 2.048              | 3                       | 0.15 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR440BRZ <sup>1</sup>        | 2.048              | 1                       | 0.05 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR440BRZ-REEL7 <sup>1</sup>  | 2.048              | 1                       | 0.05 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR441ARZ <sup>1</sup>        | 2.500              | 3                       | 0.12 | 10                                       | 8-Lead SOIC_N       | R02      | –40°C to +125°C   | R-8            |
| ADR441ARZ-REEL7 <sup>1</sup>  | 2.500              | 3                       | 0.12 | 10                                       | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR441ARMZ <sup>1</sup>       | 2.500              | 3                       | 0.12 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR441ARMZ-REEL7 <sup>1</sup> | 2.500              | 3                       | 0.12 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR441BRZ <sup>1</sup>        | 2.500              | 1                       | 0.04 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR441BRZ-REEL7 <sup>1</sup>  | 2.500              | 1                       | 0.04 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR443ARZ <sup>1</sup>        | 3.000              | 4                       | 0.13 | 10                                       | 8-Lead SOIC_N       | R03      | –40°C to +125°C   | R-8            |
| ADR443ARZ-REEL7 <sup>1</sup>  | 3.000              | 4                       | 0.13 | 10                                       | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR443ARMZ <sup>1</sup>       | 3.000              | 4                       | 0.13 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR443ARMZ-REEL7 <sup>1</sup> | 3.000              | 4                       | 0.13 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR443BRZ <sup>1</sup>        | 3.000              | 1.2                     | 0.04 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR443BRZ-REEL7 <sup>1</sup>  | 3.000              | 1.2                     | 0.04 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR444ARZ <sup>1</sup>        | 4.096              | 5                       | 0.13 | 10                                       | 8-Lead SOIC_N       | R04      | –40°C to +125°C   | R-8            |
| ADR444ARZ-REEL7 <sup>1</sup>  | 4.096              | 5                       | 0.13 | 10                                       | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR444ARMZ <sup>1</sup>       | 4.096              | 5                       | 0.13 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR444ARMZ-REEL7 <sup>1</sup> | 4.096              | 5                       | 0.13 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR444BRZ <sup>1</sup>        | 4.096              | 1.6                     | 0.04 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR444BRZ-REEL7 <sup>1</sup>  | 4.096              | 1.6                     | 0.04 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR445ARZ <sup>1</sup>        | 5.000              | 6                       | 0.12 | 10                                       | 8-Lead SOIC_N       | R05      | –40°C to +125°C   | R-8            |
| ADR445ARZ-REEL7 <sup>1</sup>  | 5.000              | 6                       | 0.12 | 10                                       | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR445ARMZ <sup>1</sup>       | 5.000              | 6                       | 0.12 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR445ARMZ-REEL7 <sup>1</sup> | 5.000              | 6                       | 0.12 | 10                                       | 8-Lead MSOP         |          | –40°C to +125°C   | RM-8           |
| ADR445BRZ <sup>1</sup>        | 5.000              | 2                       | 0.04 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |
| ADR445BRZ-REEL7 <sup>1</sup>  | 5.000              | 2                       | 0.04 | 3  | 8-Lead SOIC_N       |          | –40°C to +125°C   | R-8            |

<sup>1</sup> Z = Pb-free part.

## **NOTES**

Purchase of licensed I<sup>2</sup>C components of Analog Devices or one of its sublicensed Associated Companies conveys a license for the purchaser under the Philips I<sup>2</sup>C Patent Rights to use these components in an I<sup>2</sup>C system, provided that the system conforms to the I<sup>2</sup>C Standard Specification as defined by Philips.