# LOW NOISE, VERY LOW DRIFT, PRECISION VOLTAGE REFERENCE

## FEATURES

- **Qualified for Automotive Applications**
- **Low Temperature Drift**
  - **High Grade: 3 ppm/°C (max)**
  - **Standard Grade: 8 ppm/°C (max)**
- **High Accuracy**
  - **High Grade: 0.05% (max)**
  - **Standard Grade: 0.1% (max)**
- **Low Noise: 3 $\mu V_{PP}$/V**
- **High Output Current: ±10 mA**
- **Temperature Range: –40°C to 125°C**

## APPLICATIONS

- **16-Bit Data Acquisition Systems**
- **ATE Equipment**
- **Industrial Process Control**
- **Medical Instrumentation**
- **Optical Control Systems**
- **Precision Instrumentation**

## DESCRIPTION

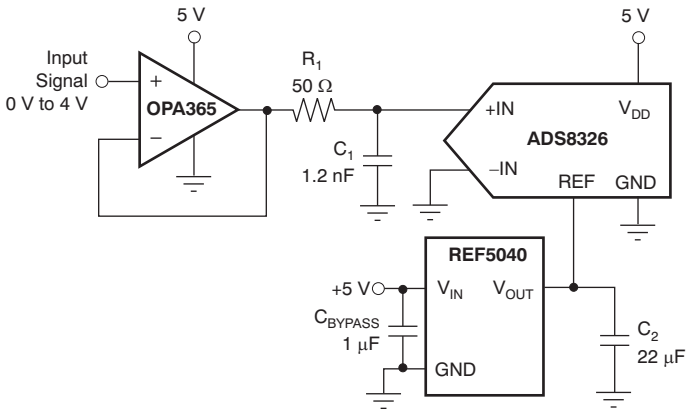
The REF50xx is a family of low-noise, low-drift, very high precision voltage references. These references are capable of both sinking and sourcing, and are very robust with regard to line and load changes.

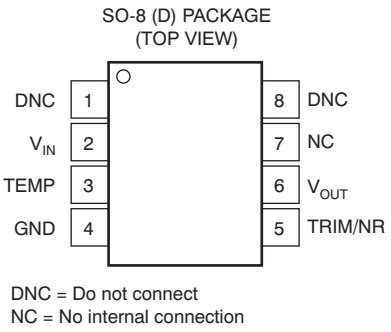
Excellent temperature drift (3 ppm/°C) and high accuracy (0.05%) are achieved using proprietary design techniques. These features combined with very low noise make the REF50xx family ideal for use in high-precision data acquisition systems.

Each reference voltage is available in both standard- and high-grade versions. They are offered in SO-8 packages and are specified from –40°C to 125°C.

**REF50xx Family**

| MODEL | OUTPUT VOLTAGE |
|---|---|
| REF5020 | 2.048 V |
| REF5025 | 2.5 V |
| REF5030 | 3 V |
| REF5040 | 4.096 V |
| REF5045 | 4.5 V |
| REF5050 | 5 V |

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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.

## PACKAGE/ORDERING INFORMATION(1)(2)

| PRODUCT | OUTPUT VOLTAGE | PACKAGE-LEAD | PACKAGE DESIGNATOR | PACKAGE MARKING |
|---|---|---|---|---|
| **STANDARD GRADE (8 ppm, 0.1%)** | | | | |
| REF5020A | 2.048 V | SO-8 | D | RFQ5020 |
| REF5025A | 2.5 V | SO-8 | D | RFQ5025 |
| REF5030A | 3.0 V | SO-8 | D | PREVIEW |
| REF5040A | 4.096 V | SO-8 | D | PREVIEW |
| REF5045A | 4.5 V | SO-8 | D | RFQ5045 |
| REF5050A | 5.0 V | SO-8 | D | PREVIEW |
| **HIGH GRADE (3 ppm, 0.05%)** | | | | |
| REF5020I | 2.048 V | SO-8 | D | RFQ5020 |
| REF5025I | 2.5 V | SO-8 | D | PREVIEW |
| REF5030I | 3.0 V | SO-8 | D | PREVIEW |
| REF5040I | 4.096 V | SO-8 | D | PREVIEW |
| REF5045I | 4.5 V | SO-8 | D | PREVIEW |
| REF5050I | 5.0 V | SO-8 | D | PREVIEW |

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.
(2) Package drawings, thermal data, and symbolization are available at www.ti.com/packaging.

## ABSOLUTE MAXIMUM RATINGS(1)

| PARAMETER | | REF50xx | UNIT |
|---|---|---|---|
| Input Voltage | | +18 | V |
| Output Short-Circuit | | 30 | mA |
| Operating Temperature Range | | –55 to +125 | °C |
| Storage Temperature Range | | –65 to +150 | °C |
| Junction Temperature ($T_J$ max) | | +150 | °C |
| ESD Rating | Human Body Model (HBM) | 3000 | V |
| | Charged Device Model (CDM) | 1000 | V |

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.


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## ELECTRICAL CHARACTERISTICS: PER DEVICE

**Boldface** limits apply over the specified temperature range, **$T_A$ = –40°C to 125°C.**
$T_A$ = 25°C, $I_{LOAD}$ = 0, $C_L$ = 1 µF, $V_{IN}$ = ($V_{OUT}$ + 0.2 V) to 18 V (unless otherwise noted).

| PARAMETER | CONDITIONS | PER DEVICE MIN | PER DEVICE TYP | PER DEVICE MAX | UNIT |
|---|---|---|---|---|---|
| **REF5020 ($V_{OUT}$ = 2.048 V)(1)** | | | | | |
| **OUTPUT VOLTAGE** | | | | | |
| Output voltage $V_{OUT}$ | 2.7 V < $V_{IN}$ < 18 V | | 2.048 | | V |
| Initial accuracy: High grade | | –0.05 | | 0.05 | % |
| Standard grade | | –0.1 | | 0.1 | % |
| **NOISE** | | | | | |
| Output voltage noise | f = 0.1 Hz to 10 Hz | | 6 | | $\mu V_{PP}$ |
| **REF5025 ($V_{OUT}$ = 2.5 V)** | | | | | |
| **OUTPUT VOLTAGE** | | | | | |
| Output voltage $V_{OUT}$ | | | 2.5 | | V |
| Initial accuracy: High grade | | –0.05 | | 0.05 | % |
| Standard grade | | –0.1 | | 0.1 | % |
| **NOISE** | | | | | |
| Output Voltage Noise | f = 0.1 Hz to 10 Hz | | 7.5 | | $\mu V_{PP}$ |
| **REF5030 ($V_{OUT}$ = 3 V)** | | | | | |
| **OUTPUT VOLTAGE** | | | | | |
| Output voltage $V_{OUT}$ | | | 3.0 | | V |
| Initial accuracy: High grade | | –0.05 | | 0.05 | % |
| Standard grade | | –0.1 | | 0.1 | % |
| **NOISE** | | | | | |
| Output voltage noise | f = 0.1 Hz to 10 Hz | | 9 | | $\mu V_{PP}$ |
| **REF5040 ($V_{OUT}$ = 4.096 V)** | | | | | |
| **OUTPUT VOLTAGE** | | | | | |
| Output voltage $V_{OUT}$ | | | 4.096 | | V |
| Initial accuracy: High grade | | –0.05 | | 0.05 | % |
| Standard grade | | –0.1 | | 0.1 | % |
| **NOISE** | | | | | |
| Output voltage noise | f = 0.1 Hz to 10 Hz | | 12 | | $\mu V_{PP}$ |
| **REF5045 ($V_{OUT}$ = 4.5 V)** | | | | | |
| **OUTPUT VOLTAGE** | | | | | |
| Output voltage $V_{OUT}$ | | | 4.5 | | V |
| Initial accuracy: High grade | | –0.05 | | 0.05 | % |
| Standard grade | | –0.1 | | 0.1 | % |
| **NOISE** | | | | | |
| Output voltage noise | f = 0.1 Hz to 10 Hz | | 13.5 | | $\mu V_{PP}$ |
| **REF5050 ($V_{OUT}$ = 5 V)** | | | | | |
| **OUTPUT VOLTAGE** | | | | | |
| Output voltage $V_{OUT}$ | | | 5.0 | | V |
| Initial accuracy: High grade | | –0.05 | | 0.05 | % |
| Standard grade | | –0.1 | | 0.1 | % |
| **NOISE** | | | | | |
| Output voltage noise | f = 0.1 Hz to 10 Hz | | 15 | | $\mu V_{PP}$ |

(1) For $V_{OUT}$ ≤ 2.5 V, the minimum supply voltage is 2.7 V.

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## ELECTRICAL CHARACTERISTICS: ALL DEVICES

**Boldface** limits apply over the specified temperature range, **$T_A$ = –40°C to 125°C.**
$T_A$ = 25°C, $I_{LOAD}$ = 0, $C_L$ = 1 µF, $V_{IN}$ = ($V_{OUT}$ + 0.2 V) to 18 V (unless otherwise noted).

| PARAMETER | CONDITIONS | REF50xx | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| **OUTPUT VOLTAGE TEMPERATURE DRIFT** | | | | | |
| **Output voltage temperature drift $dV_{OUT}/dT$** | | | | | |
| **High grade** | | | **2.5** | **3** | **ppm/°C** |
| **Standard grade** | | | **3** | **8** | **ppm/°C** |
| **LINE REGULATION** | | | | | |
| Line regulation $dV_{OUT}/dV_{IN}$ | | | | | |
| REF5020(1) only | $V_{IN}$ = 2.7 V to 18 V | | 0.1 | 1 | ppm/V |
| All other devices | $V_{IN}$ = $V_{OUT}$ + 0.2 V | | 0.1 | 1 | ppm/V |
| **Over temperature** | | | **0.2** | **1** | **ppm/V** |
| **LOAD REGULATION** | | | | | |
| Load regulation $dV_{OUT}/dI_{LOAD}$ | –10 mA < $I_{LOAD}$ < +10 mA | | | | |
| REF5020 Only | $V_{IN}$ = 3 V | | 20 | 30 | ppm/mA |
| All other devices | $V_{IN}$ = $V_{OUT}$ + 0.75 V | | 20 | 30 | ppm/mA |
| **Over temperature** | | | | **50** | **ppm/mA** |
| **SHORT-CIRCUIT CURRENT** | | | | | |
| Short-circuit current $I_{SC}$ | $V_{OUT}$ = 0 | | 25 | | mA |
| **TEMP PIN** | | | | | |
| Voltage output | At $T_A$ = 25°C | | 575 | | mV |
| **Temperature sensitivity** | | | **2.64** | | **mV/°C** |
| **TURN-ON SETTLING TIME** | | | | | |
| Turn-on settling time | To 0.1% with $C_L$ = 1 µF | | 200 | | µs |
| **POWER SUPPLY** | | | | | |
| Supply voltage $V_S$ | See Note (1) | $V_{OUT}$ + 0.2(1) | | 18 | V |
| Quiescent current | | | 0.8 | 1 | mA |
| **Over temperature** | | | | **1.2** | **mA** |
| **TEMPERATURE RANGE** | | | | | |
| Specified range | | –40 | | 125 | °C |
| Operating range | | –55 | | 125 | °C |
| Thermal resistance $\theta_{JA}$ | | | | | |
| SO-8 | | | 150 | | °C/W |

(1) For $V_{OUT}$ ≤ 2.5 V, the minimal supply voltage is 2.7 V.


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## TYPICAL CHARACTERISTICS

$T_A$ = 25°C, $I_{LOAD}$ = 0, $V_S$ = $V_{OUT}$ + 0.2 V (unless otherwise noted). For $V_{OUT}$ ≤ 2.5 V, the minimum supply voltage is 2.7 V.

**TEMPERATURE DRIFT (0°C to 85°C)**

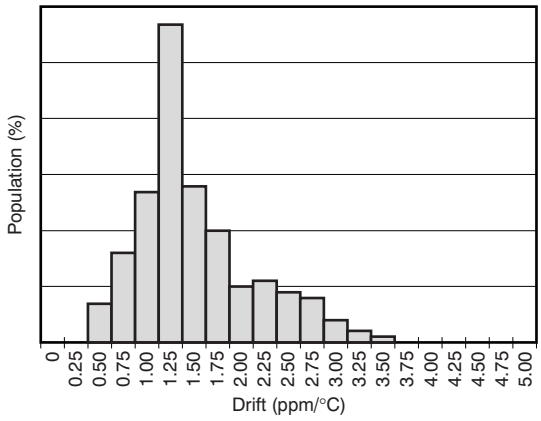


**Figure 1.**

**TEMPERATURE DRIFT (–40°C to 125°C)**

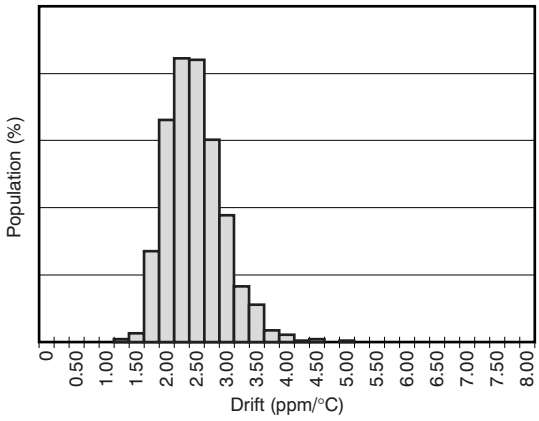


**Figure 2.**

**OUTPUT VOLTAGE INITIAL ACCURACY**

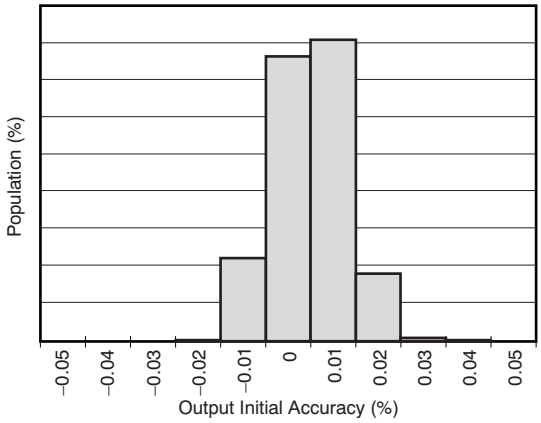


**Figure 3.**

**OUTPUT VOLTAGE ACCURACY vs TEMPERATURE**

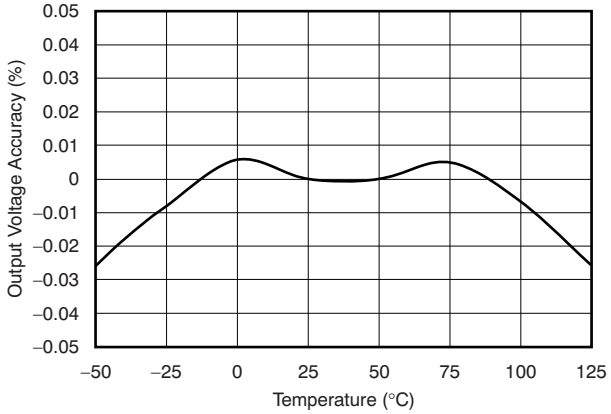


**Figure 4.**

**POWER-SUPPLY REJECTION RATIO vs FREQUENCY**

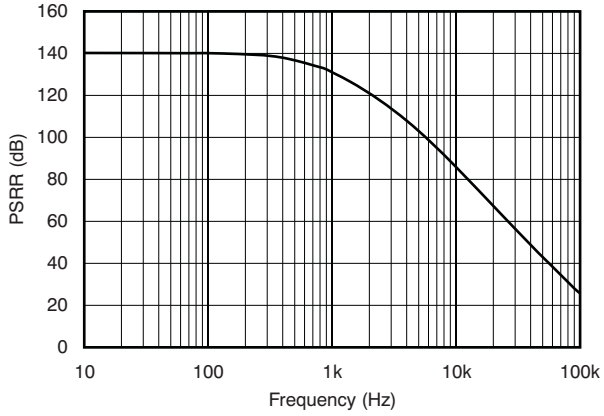


**Figure 5.**

**DROPOUT VOLTAGE vs LOAD CURRENT**

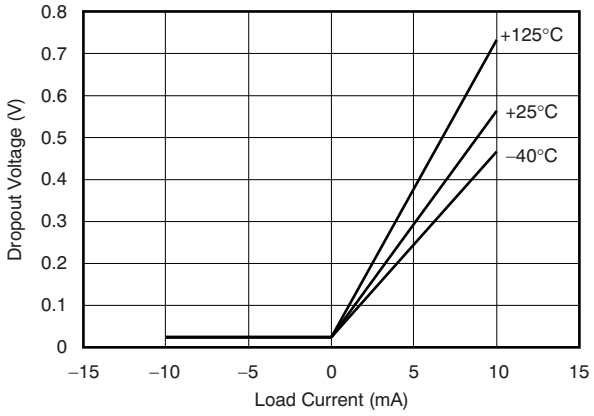


**Figure 6.**

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## TYPICAL CHARACTERISTICS (continued)

$T_A$ = 25°C, $I_{LOAD}$ = 0, $V_S$ = $V_{OUT}$ + 0.2 V (unless otherwise noted). For $V_{OUT}$ ≤ 2.5 V, the minimum supply voltage is 2.7 V.

**REF5025 OUTPUT VOLTAGE vs LOAD CURRENT**

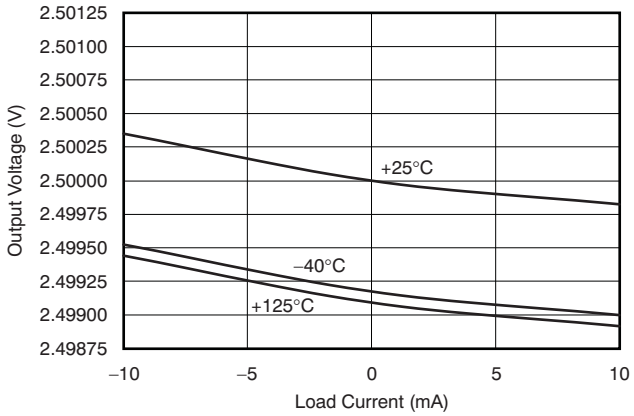


**Figure 7.**

**TEMP PIN OUTPUT VOLTAGE vs TEMPERATURE**

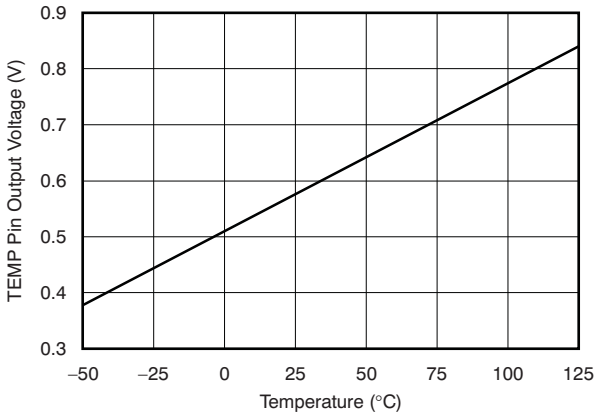


**Figure 8.**

**QUIESCENT CURRENT vs TEMPERATURE**

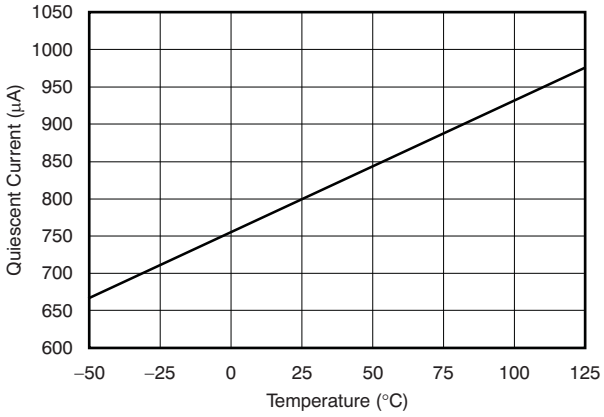


**Figure 9.**

**QUIESCENT CURRENT vs INPUT VOLTAGE**

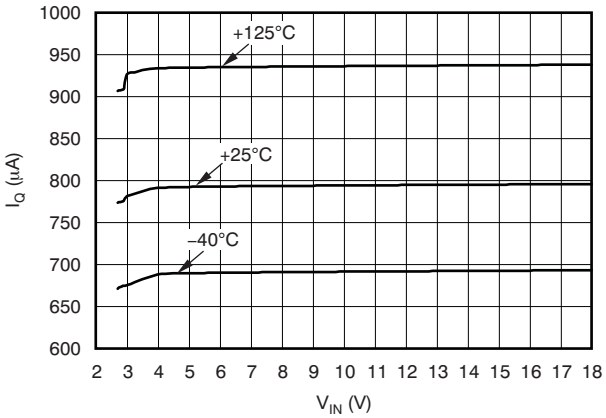


**Figure 10.**

**LINE REGULATION vs TEMPERATURE**

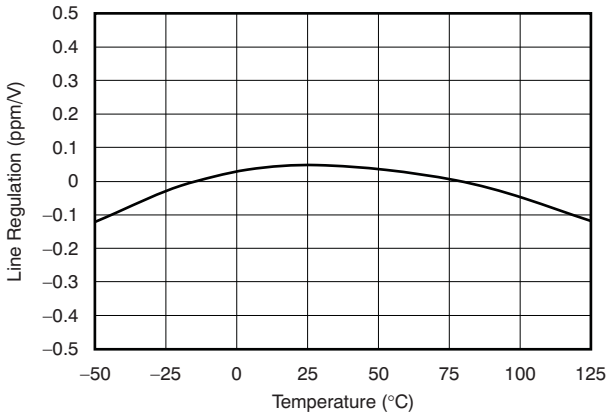


**Figure 11.**

**SHORT-CIRCUIT CURRENT vs TEMPERATURE**

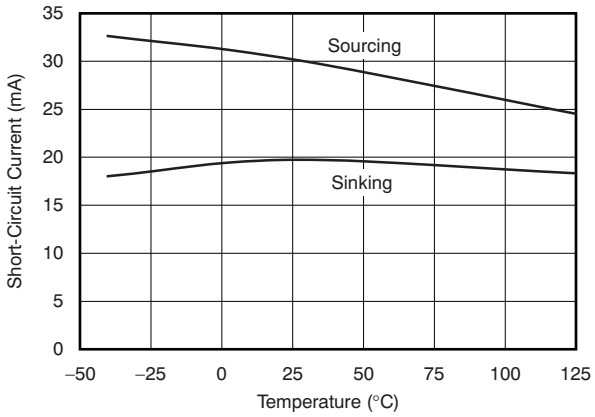


**Figure 12.**


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## TYPICAL CHARACTERISTICS (continued)

$T_A$ = 25°C, $I_{LOAD}$ = 0, $V_S$ = $V_{OUT}$ + 0.2 V (unless otherwise noted). For $V_{OUT}$ ≤ 2.5 V, the minimum supply voltage is 2.7 V.

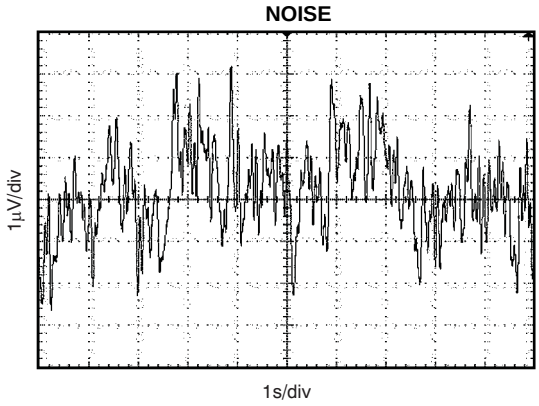


Figure 13.

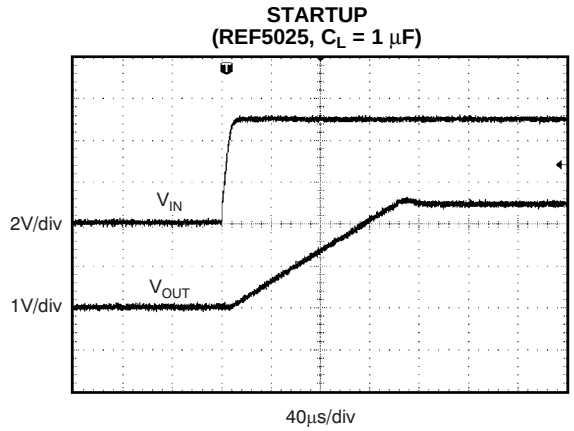


Figure 14.

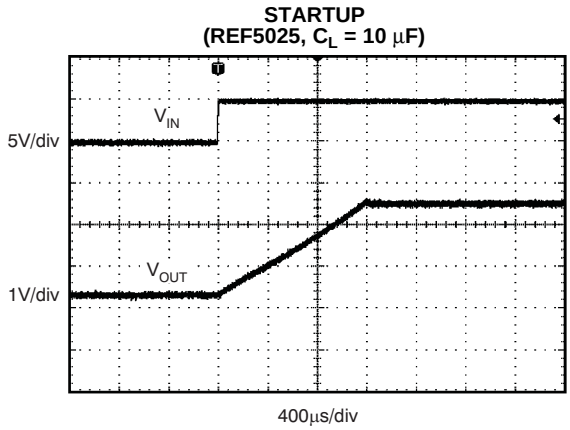


Figure 15.

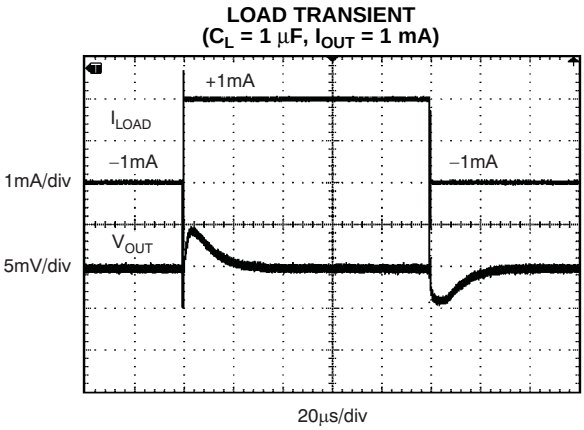


Figure 16.

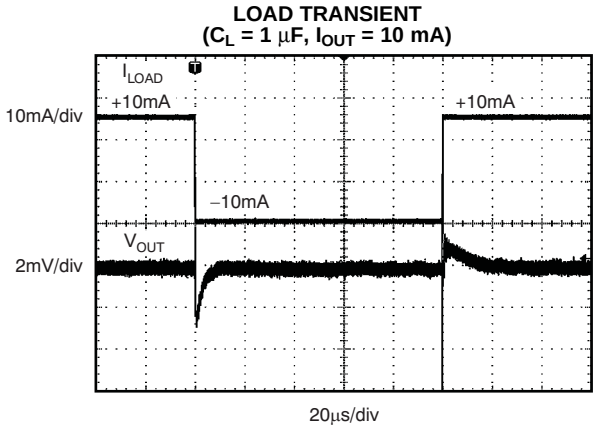


Figure 17.

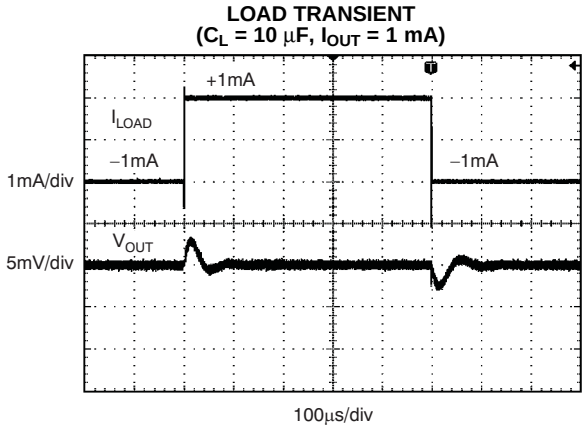


Figure 18.



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## TYPICAL CHARACTERISTICS (continued)

$T_A$ = 25°C, $I_{LOAD}$ = 0, $V_S$ = $V_{OUT}$ + 0.2 V (unless otherwise noted). For $V_{OUT}$ ≤ 2.5 V, the minimum supply voltage is 2.7 V.

**LOAD TRANSIENT**
**($C_L$ = 10 µF, $I_{OUT}$ = 10 mA)**

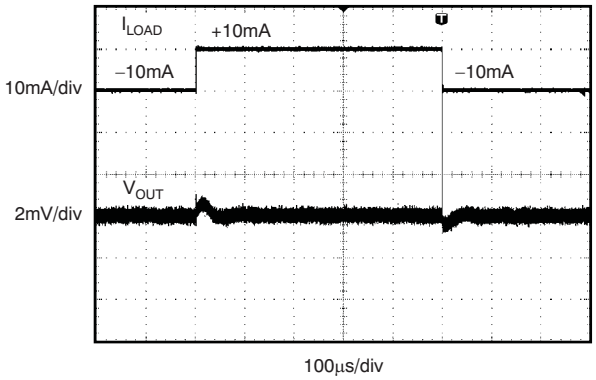


**Figure 19.**

**LINE TRANSIENT**
**($C_L$ = 1 µF)**

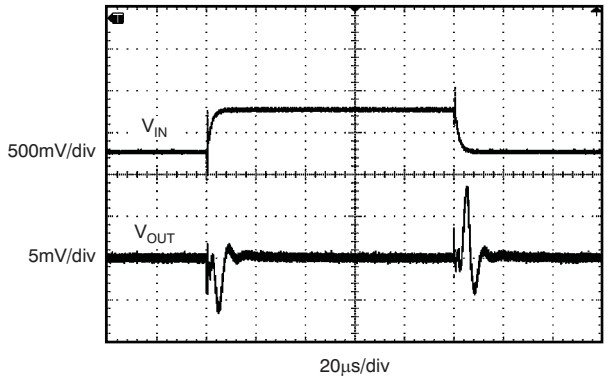


**Figure 20.**

**LINE TRANSIENT**
**($C_L$ = 10 µF)**

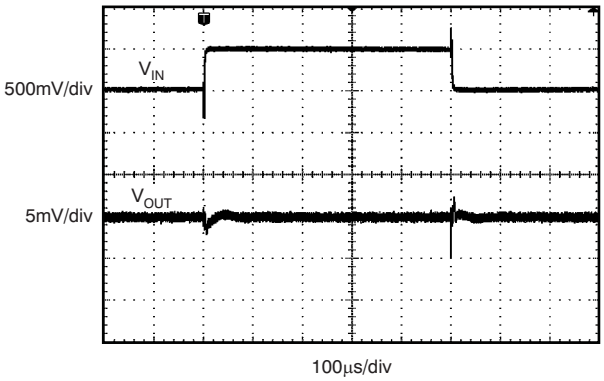


**Figure 21.**


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## APPLICATION INFORMATION

The REF50xx is family of low-noise, precision bandgap voltage references that are specifically designed for excellent initial voltage accuracy and drift. Figure 22 shows a simplified block diagram of the REF50xx.

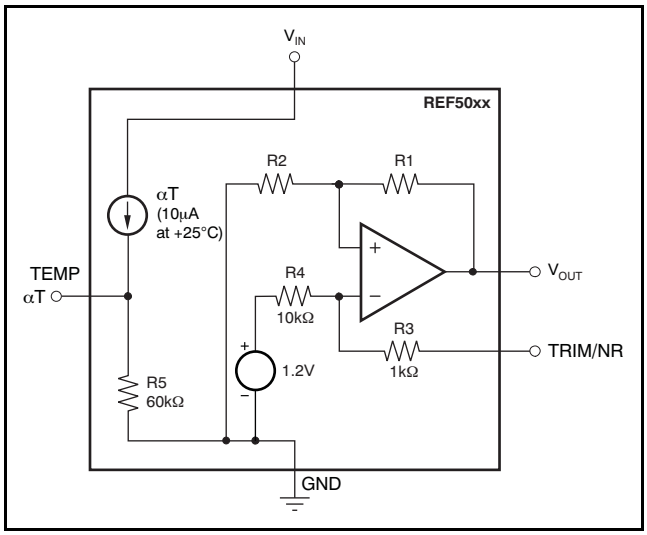


**Figure 22. REF50xx Simplified Block Diagram**

### BASIC CONNECTIONS

Figure 23 shows the typical connections for the REF50xx. A supply bypass capacitor ranging between 1 μF to 10 μF is recommended. A 1-μF to 50-μF, low-ESR output capacitor ($C_L$) must be connected from $V_{OUT}$ to GND. The ESR value should be less than or equal to 1.5 Ω. The ESR minimizes gain peaking of the internal 1.2-V reference and thus reduces noise at the $V_{OUT}$ pin.

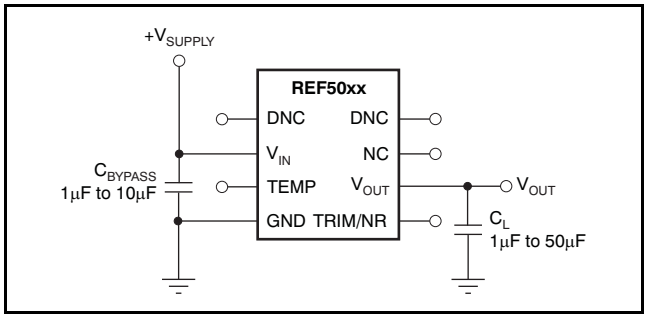


**Figure 23. Basic Connections**

### SUPPLY VOLTAGE

The REF50xx family of voltage references features extremely low dropout voltage. With the exception of the REF5020, which has a minimum supply requirement of 2.7 V, these references can be operated with a supply of 200 mV above the output voltage in an unloaded condition. For loaded conditions, a typical dropout voltage versus load plot is shown in Figure 6 of *Typical Characteristics*.

### USING THE TRIM/NR PIN

The REF50xx provides a very accurate voltage output. However, $V_{OUT}$ can be adjusted to reduce noise and shift the output voltage from the nominal value by configuring the trim and noise reduction pin (TRIM/NR, pin 5). The TRIM/NR pin provides a ±15-mV adjustment of the device bandgap, which produces a ±15-mV change on the $V_{OUT}$ pin. Figure 24 shows a typical circuit using the TRIM/NR pin to adjust $V_{OUT}$. When using this technique, the temperature coefficients of the resistors can degrade the temperature drift at the output.

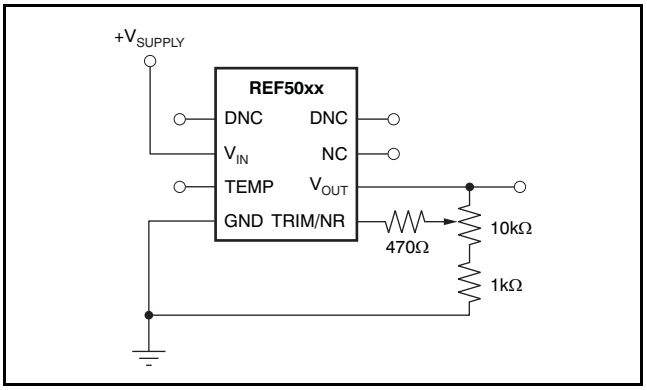


**Figure 24. $V_{OUT}$ Adjustment Using TRIM/NR Pin**

The REF50xx allows access to the bandgap through the TRIM/NR pin. Placing a capacitor from the TRIM/NR pin to GND (as Figure 25 illustrates) in combination with the internal 1-kΩ resistor creates a low-pass filter that lowers the overall noise measured on the $V_{OUT}$ pin. A capacitance of 1 μF is suggested for a low-pass filter with a corner frequency of 14.5 Hz. Higher capacitance results in a lower cutoff frequency.

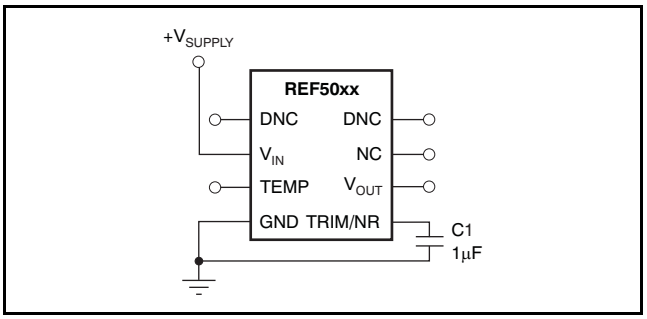


**Figure 25. Noise Reduction Using TRIM/NR Pin**



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## TEMPERATURE DRIFT

The REF50xx is designed for minimal drift error, which is defined as the change in output voltage over temperature. The drift is calculated using the box method, as described by the following equation:

$$\text{Drift} = \left( \frac{V_{OUTMAX} - V_{OUTMIN}}{V_{OUT} \times \text{Temp Range}} \right) \times 10^6 (\text{ppm}) \quad (1)$$

The REF50xx features a maximum drift coefficient of 3 ppm/°C for the high-grade version, and 8 ppm/°C for the standard-grade.

## TEMPERATURE MONITORING

The temperature output terminal (TEMP, pin 3) provides a temperature-dependent voltage output with approximately 60-kΩ source impedance. As seen in Figure 8, the output voltage follows the nominal relationship:

$V_{TEMP\ PIN} = 509\ mV + 2.64 \times T(°C)$

This pin indicates general chip temperature, accurate to approximately ±15°C. Although it is not generally suitable for accurate temperature measurements, it can be used to indicate temperature changes or for temperature compensation of analog circuitry. A temperature change of 30°C corresponds to an approximate 79-mV change in voltage at the TEMP pin.

The TEMP pin has high output impedance (see Figure 22). Loading this pin with a low-impedance circuit induces a measurement error; however, it does not have any effect on $V_{OUT}$ accuracy. To avoid errors caused by low-impedance loading, buffer the TEMP pin output with a suitable low-temperature drift op amp, such as the OPA333, OPA335, or OPA376, as shown in Figure 26.

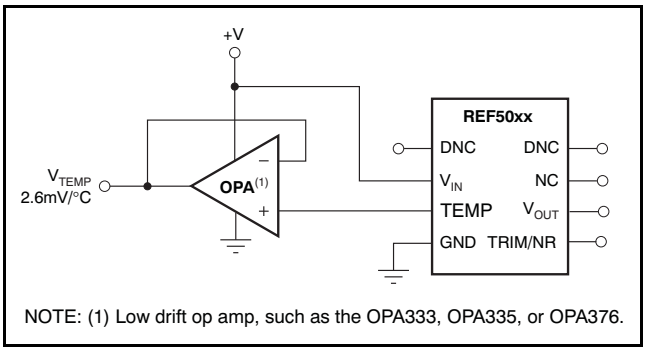


**Figure 26. Buffering the TEMP Pin Output**

## POWER DISSIPATION

The REF50xx family is specified to deliver current loads of ±10 mA over the specified input voltage range. The temperature of the device increases according to the equation:

$T_J = T_A + P_D \times \theta_{JA}$

Where:

$T_J$ = Junction temperature (°C)
$T_A$ = Ambient temperature (°C)
$P_D$ = Power dissipated (W)
$\theta_{JA}$ = Junction-to-ambient thermal resistance (°C/W)

The REF50xx junction temperature must not exceed the absolute maximum rating of 150°C.

## NOISE PERFORMANCE

Typical 0.1-Hz to 10-Hz voltage noise for each member of the REF50xx family is specified in the *Electrical Characteristics: Per Device* table. The noise voltage increases with output voltage and operating temperature. Additional filtering can be used to improve output noise levels, although care should be taken to ensure the output impedance does not degrade performance.


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## APPLICATION CIRCUITS

### NEGATIVE REFERENCE VOLTAGE

For applications requiring a negative and positive reference voltage, the REF50xx and OPA735 can be used to provide a dual-supply reference from a 5-V supply. Figure 27 shows the REF5025 used to provide a 2.5-V supply reference voltage. The low drift performance of the REF50xx complements the low offset voltage and zero drift of the OPA735 to provide an accurate solution for split-supply applications. Care must be taken to match the temperature coefficients of $R_1$ and $R_2$.

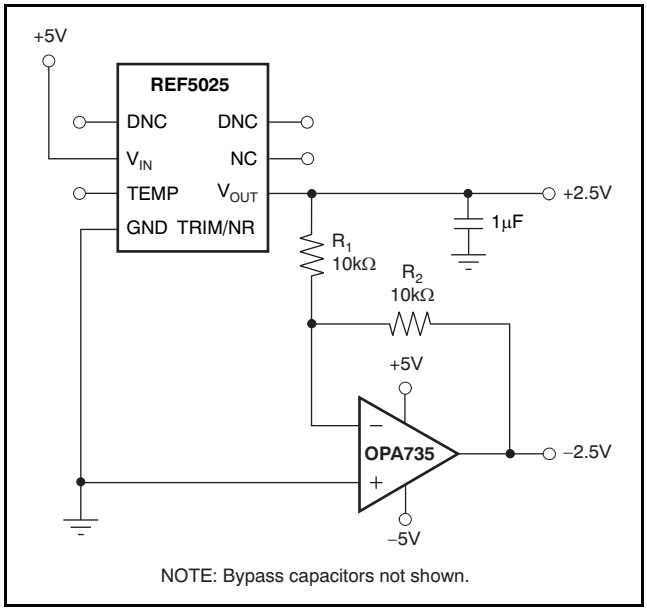


**Figure 27. The REF5025 and OPA735 Create Positive and Negative Reference Voltages**

### DATA ACQUISITION

Data acquisition systems often require stable voltage references to maintain accuracy. The REF50xx family features low noise, very low drift, and high initial accuracy for high-performance data converters. Figure 28 shows the REF5040 in a basic data acquisition system.

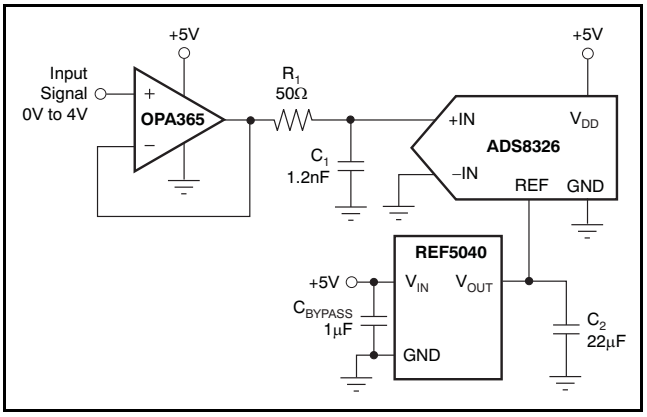


**Figure 28. Basic Data Acquisition System**



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## Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from Revision A (December, 2008) to Revision B | Page |
|---|---|
| • Changed *Storage Temperature Range* absolute minimum value from –55°C to –65°C | 2 |
| • Added test condition to *Line regulation, All other devices* specification | 4 |
| • Added *Load regulation* test condition and *Over temperature* specifications | 4 |
| • Added typical characteristic graph, *Quiescent Current vs Input Voltage* (Figure 10) | 6 |


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## PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/Ball Finish | MSL Peak Temp (3) |
|---|---|---|---|---|---|---|---|---|
| REF5020AQDRQ1 | PREVIEW | SOIC | D | 8 | 2500 | TBD | Call TI | Call TI |
| REF5025AQDRQ1 | PREVIEW | SOIC | D | 8 | 2500 | TBD | Call TI | Call TI |
| REF5045AQDRQ1 | PREVIEW | SOIC | D | 8 | 2500 | TBD | Call TI | Call TI |

(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) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
**TBD:** The Pb-Free/Green conversion plan has not been defined.
**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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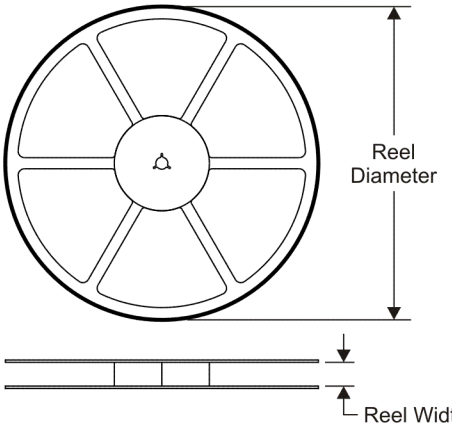
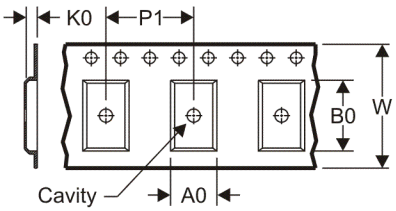
## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

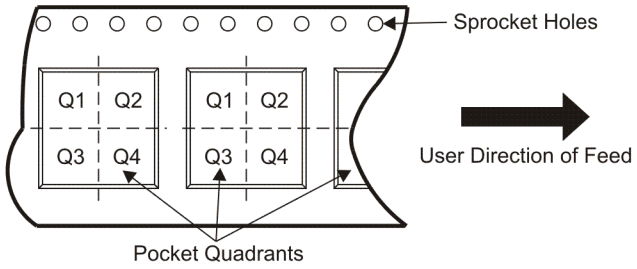



**TAPE DIMENSIONS**




| | |
|---|---|
| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REF5025AQDRQ1 | SOIC | D | 8 | 2500 | 330.0 | 12.4 | 6.4 | 5.2 | 2.1 | 8.0 | 12.0 | Q1 |
| REF5045AQDRQ1 | SOIC | D | 8 | 2500 | 330.0 | 12.4 | 6.4 | 5.2 | 2.1 | 8.0 | 12.0 | Q1 |



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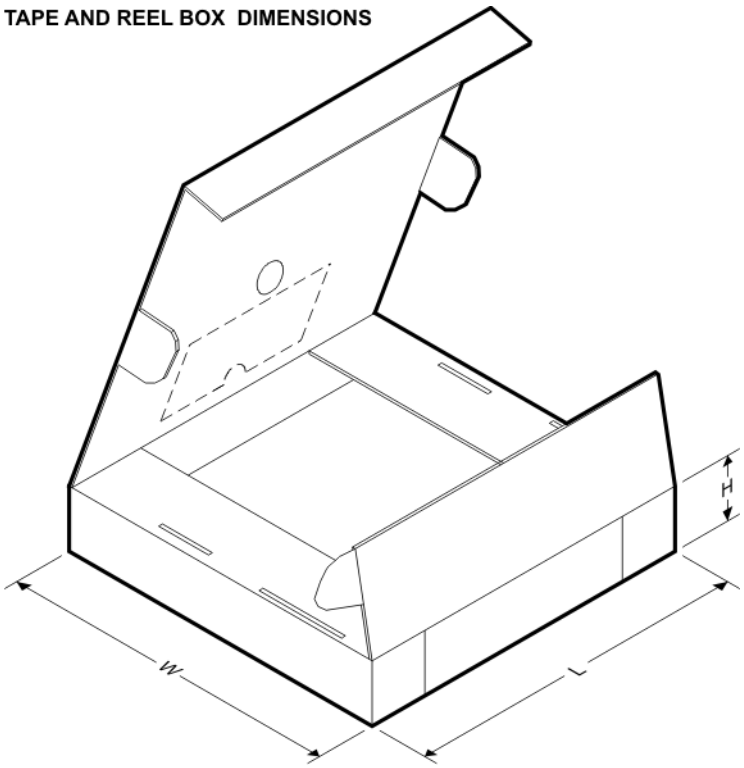
TAPE AND REEL BOX DIMENSIONS




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| REF5025AQDRQ1 | SOIC | D | 8 | 2500 | 346.0 | 346.0 | 29.0 |
| REF5045AQDRQ1 | SOIC | D | 8 | 2500 | 346.0 | 346.0 | 29.0 |



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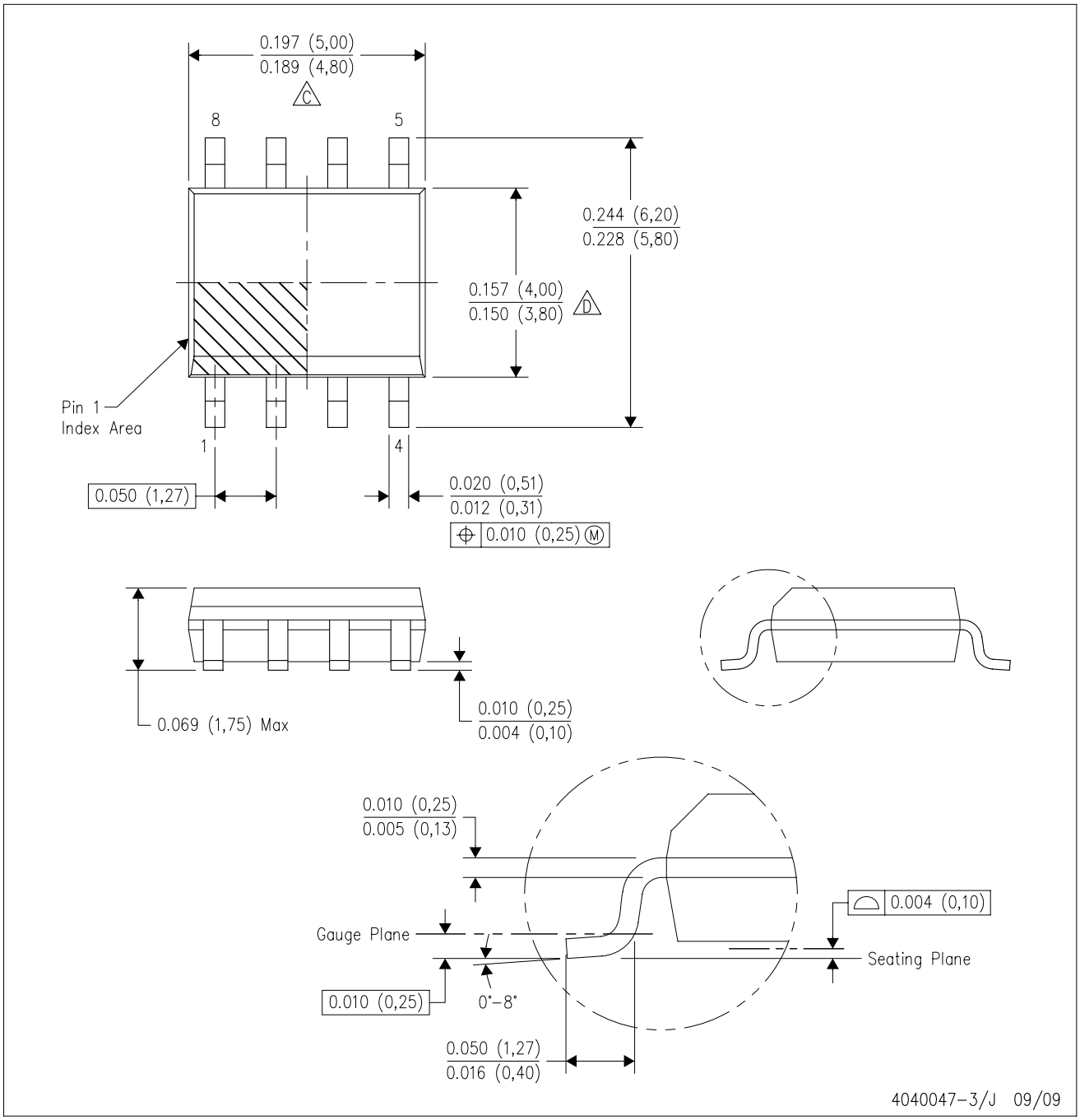
D (R–PDSO–G8) PLASTIC SMALL–OUTLINE PACKAGE




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 .006 (0,15) per end.
D. Body width does not include interlead flash. Interlead flash shall not exceed .017 (0,43) per side.
E. Reference JEDEC MS–012 variation AA.



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