National Semiconductor

May 30, 2008

# LM4030
# SOT-23 Ultra-High Precision Shunt Voltage Reference

## General Description

The LM4030 is an ultra-high precision shunt voltage reference, having exceptionally high initial accuracy (0.05%) and temperature stability (10ppm/°C). The LM4030 is available with fixed voltage options of 2.5V and 4.096V. Despite the tiny SOT23 package, the LM4030 exhibits excellent thermal hysteresis (75ppm) and long-term stability (40ppm) as well as immunity to board stress effects.

The LM4030 is designed to operate without an external capacitor, but any capacitor up to 10µF may be used. The LM4030 can be powered off as little as 120µA (max) but is capable of shunting up to 30mA continuously. As with any shunt reference, the LM4030 can be powered off of virtually any supply and is a simple way to generate a highly accurate system reference.

The LM4030 is available in three grades (A, B, and C). The best grade devices (A) have an initial accuracy of 0.05% with guaranteed temperature coefficient of 10 ppm/°C or less, while the lowest grade parts (C) have an initial accuracy of 0.15% and a temperature coefficient of 30 ppm/°C.

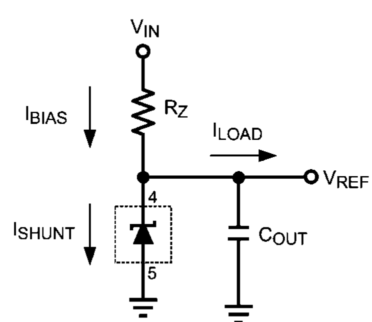
## Features

- High output voltage accuracy 0.05%
- Low temperature coefficient 10 ppm/°C
- Extended temperature operation -40-125°C
- Excellent thermal hysteresis, 75ppm
- Excellent long-term stability, 40ppm
- High immunity to board stress effects
- Capable of handling 50 mA transients
- Voltage options 2.5V, 4.096V
- SOT23-5 Package

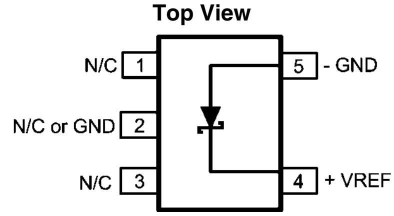
## Applications

- Data Acquisition/Signal path
- Test and Measurement
- Automotive & Industrial
- Communications
- Instrumentation
- Power Management

## Typical Application Circuit




## Connection Diagram




**SOT23-5 Package**
**NS Package Number MF05A**

## Ordering Information

| Input Output Voltage Accuracy at 25°C And Temperature Coefficient | LM4030 Supplied as 1000 units, Tape and Reel | LM4030 Supplied as 3000 units, Tape and Reel | Part Marking |
|---|---|---|---|
| 0.05%, 10 ppm/°C max (A grade) | LM4030AMF-2.5 | LM4030AMFX-2.5 | R5JA |
| | LM4030AMF-4.096 | LM4030AMFX4.096 | R5KA |
| 0.10%, 20 ppm/°C max (B grade) | LM4030BMF-2.5 | LM4030BMFX-2.5 | R5JB |
| | LM4030BMF-4.096 | LM4030BMFX4.096 | R5KB |
| 0.15%, 30 ppm/°C max (C grade) | LM4030CMF-2.5 | LM4030CMFX-2.5 | R5JC |
| | LM4030CMF-4.096 | LM4030CMFX4.096 | R5KC |

## Pin Descriptions

| Pin # | Name | Function |
|---|---|---|
| 1 | N/C | No connect pin, leave floating |
| 2 | GND, N/C | Ground or no connect |
| 3 | N/C | No connect pin, leave floating |
| 4 | VREF | Reference voltsge |
| 5 | GND | Ground |

## Absolute Maximum Ratings (Note 1)

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.**

| | |
|---|---|
| Maximum Voltage on any input | -0.3 to 6V |
| Power Dissipation ($T_A$ = 25°C) (Note 2) | 350mW |
| Storage Temperature Range | –65°C to 150°C |
| Lead Temperature (soldering, 10sec) | 260°C |
| Vapor Phase (60 sec) | 215°C |
| Infrared (15sec) | 220°C |
| ESD Susceptibility (Note 3) | |
| Human Body Model | 2kV |

## Operating Ratings

| | |
|---|---|
| Maximum Continuous Shunt Current | 30mA |
| Maximum Shunt Current (<1s) | 50mA |
| Junction Temperature Range ($T_J$) | –40°C to +125°C |

## Electrical Characteristics

### LM4030-2.5 ($V_{OUT}$ = 2.5V)

Limits in standard type are for $T_J$ = 25°C only, and limits in boldface type apply over the junction temperature ($T_J$) range of -40°C to +125°C. Minimum and Maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at $T_J$ = 25°C, and are provided for reference purposes only.

| Symbol | Parameter | Conditions | Min (Note 4) | Typ (Note 5) | Max (Note 4) | Unit |
|---|---|---|---|---|---|---|
| $V_{REF}$ | Reverse Breakdown Voltage | $I_{SHUNT}$ = 120μA | | 2.5 | | V |
| | Reverse Breakdown Voltage Tolerance ($I_{SHUNT}$ = 120μA) | | | | | |
| | LM4030A-2.5 | (A Grade - 0.05%) | -0.05 | | 0.05 | % |
| | LM4030B-2.5 | (B Grade - 0.10%) | -0.10 | | 0.10 | % |
| | LM4030C-2.5 | (C Grade - 0.15%) | -0.15 | | 0.15 | % |
| $I_{RMIN}$ | Minimum Operating Current | | | | **120** | μA |
| TC | Temperature Coefficient (Note 6) | | | | | |
| | LM4030A-2.5 | 0°C ≤ $T_J$ ≤ + 85°C | | | **10** | ppm / °C |
| | | -40°C ≤ $T_J$ ≤ +125°C | | | **20** | ppm / °C |
| | LM4030B-2.5 | -40°C ≤ $T_J$ ≤ +125°C | | | **20** | ppm / °C |
| | LM4030C-2.5 | -40°C ≤ $T_J$ ≤ +125°C | | | **30** | ppm / °C |
| $\Delta V_{REF}/\Delta I_{SHUNT}$ | Reverse Breakdown Voltage Change with Current | 160μA ≤ $I_{SHUNT}$ ≤ 30mA | | 25 | **110** | ppm / mA |
| $\Delta V_{REF}$ | Long Term Stability (Note 7) | 1000 Hrs, $T_A$ = 30°C | | 40 | | ppm |
| $V_{HYST}$ | Thermal Hysteresis (Note 8) | -40°C ≤ $T_J$ ≤ +125°C | | 75 | | ppm |
| $V_N$ | Output Noise Voltage (Note 9) | 0.1 Hz to 10 Hz | | 105 | | $\mu V_{PP}$ |

# Electrical Characteristics

## LM4030-4.096 ($V_{OUT}$ = 4.096V)

Limits in standard type are for $T_J$ = 25°C only, and limits in boldface type apply over the junction temperature ($T_J$) range of -40°C to +125°C. Minimum and Maximum limits are guaranteed through test, design, or statistical correlation. Typical values represent the most likely parametric norm at $T_J$ = 25°C, and are provided for reference purposes only.

| Symbol | Parameter | Conditions | Min (Note 4) | Typ (Note 5) | Max (Note 4) | Unit |
|---|---|---|---|---|---|---|
| $V_{REF}$ | Reverse Breakdown Voltage | $I_{SHUNT}$ = 130µA | | 4.096 | | V |
| | Reverse Breakdown Voltage Tolerance ( $I_{SHUNT}$ = 130µA) | | | | | |
| | LM4030A-4.096 | (A Grade - 0.05%) | -0.05 | | 0.05 | % |
| | LM4030B-4.096 | (B Grade - 0.10%) | -0.10 | | 0.10 | % |
| | LM4030C-4.096 | (C Grade - 0.15%) | -0.15 | | 0.15 | % |
| $I_{RMIN}$ | Minimum Operating Current | | | | **130** | µA |
| TC | Temperature Coefficient (Note 6) | | | | | |
| | LM4030A-4.096 | 0°C ≤ $T_J$ ≤ + 85°C | | | **10** | ppm / °C |
| | | -40°C ≤ $T_J$ ≤ +125°C | | | **20** | ppm / °C |
| | LM4030B-4.096 | -40°C ≤ $T_J$ ≤ +125°C | | | **20** | ppm / °C |
| | LM4030C-4.096 | -40°C ≤ $T_J$ ≤ +125°C | | | **30** | ppm / °C |
| $\Delta V_{REF}/\Delta I_{LOAD}$ | Reverse Breakdown Voltage Change with Current | 160µA ≤ $I_{SHUNT}$ ≤ 30mA | | 15 | **95** | ppm / mA |
| $\Delta V_{REF}$ | Long Term Stability (Note 7) | 1000 Hrs, $T_A$ = 30°C | | 40 | | ppm |
| $V_{HYST}$ | Thermal Hysteresis (Note 8) | -40°C ≤ $T_J$ ≤ +125°C | | 75 | | ppm |
| $V_N$ | Output Noise Voltage (Note 9) | 0.1 Hz to 10 Hz | | 165 | | $\mu V_{PP}$ |

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage may occur to the device. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications, see Electrical Characteristics.

**Note 2:** Without PCB copper enhancements. The maximum power dissipation must be de-rated at elevated temperatures and is limited by $T_{JMAX}$ (maximum junction temperature), $\theta_{J-A}$ (junction to ambient thermal resistance) and $T_A$ (ambient temperature). The maximum power dissipation at any temperature is: $P_{DissMAX} = (T_{JMAX} - T_A) / \theta_{J-A}$ up to the value listed in the Absolute Maximum Ratings. $\theta_{J-A}$ for SOT23-5 package is 220°C/W, $T_{JMAX}$ = 125°C.

**Note 3:** The human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin.

**Note 4:** Limits are 100% production tested at 25°C. Limits over the operating temperature range are guaranteed through correlation using Statistical Quality Control.

**Note 5:** Typical numbers are at 25°C and represent the most likely parametric norm.

**Note 6:** Temperature coefficient is measured by the "Box" method; i.e., the maximum $\Delta V_{REF}$ is divided by the maximum ΔT.

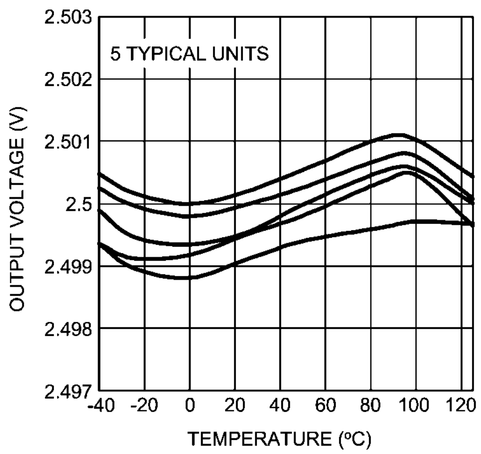
**Note 7:** Long term stability is $V_{REF}$ @25°C measured during 1000 hrs. This measurement is taken for $I_R$ = 500 µA.

**Note 8:** Thermal hysteresis is defined as the change in +25°C output voltage before and after cycling the device from (-40°C to 125°C) eight times.

**Note 9:** Low frequency peak-to-peak noise measured using first-order 0.1 Hz HPF and second-order 10 Hz LPF.

## Typical Performance Characteristics for 2.5V

**Output Voltage vs Temperature**

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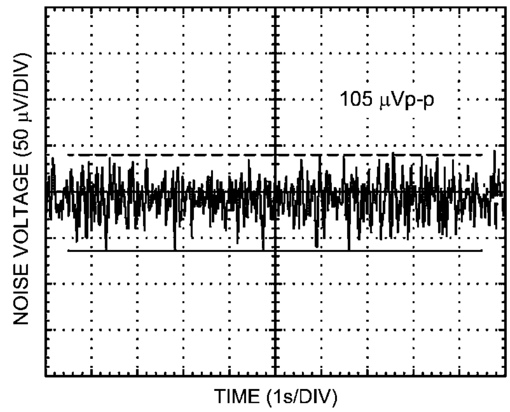
**0.1 - 10 Hz Peak-to-Peak Noise**

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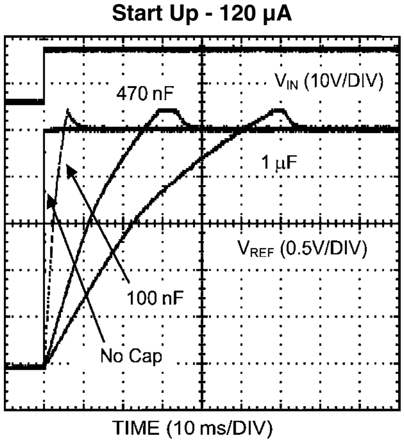
**Start Up - 120 µA**

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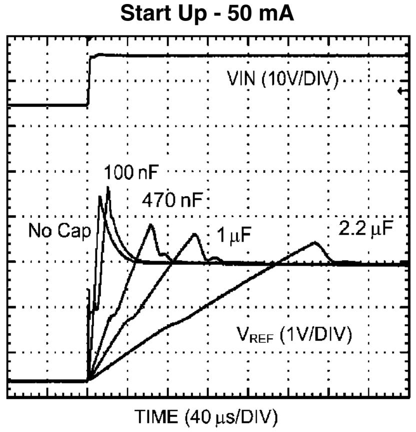
**Start Up - 50 mA**

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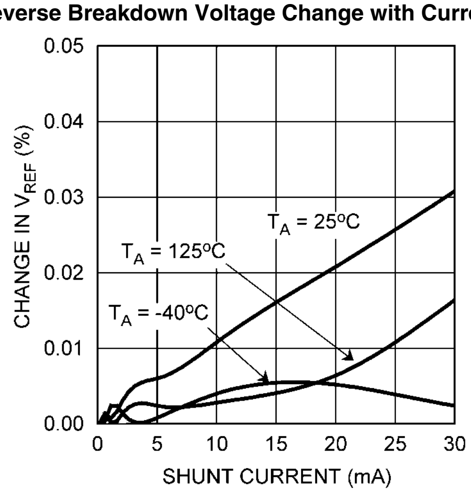
**Reverse Breakdown Voltage Change with Current**

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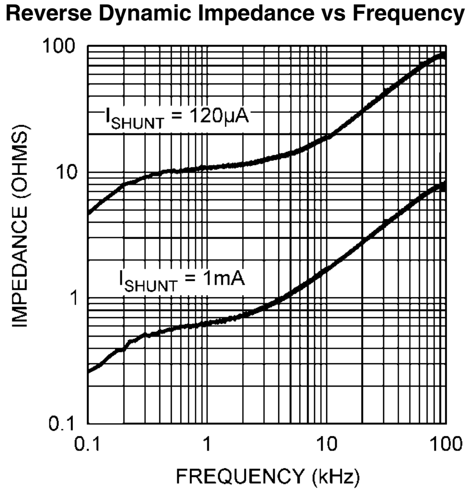
**Reverse Dynamic Impedance vs Frequency**

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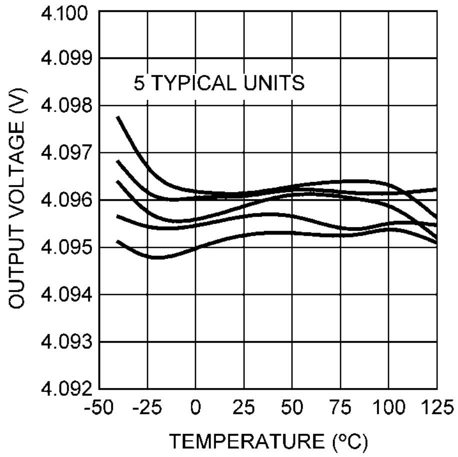
# Typical Performance Characteristics for 4.096V

**Output Voltage vs Temperature**

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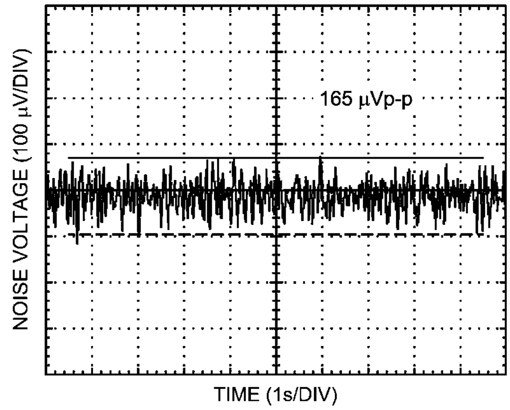
**0.1 - 10 Hz Peak-to-Peak Noise**

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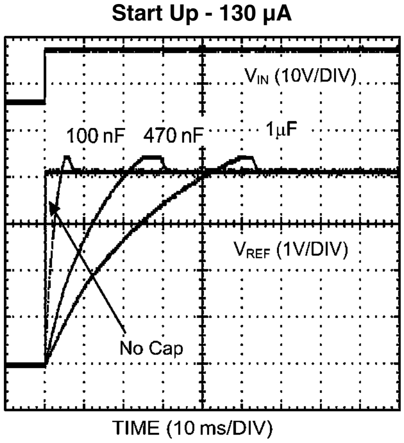
**Start Up - 130 µA**

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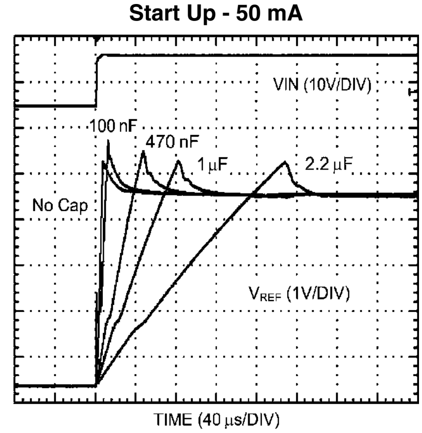
**Start Up - 50 mA**

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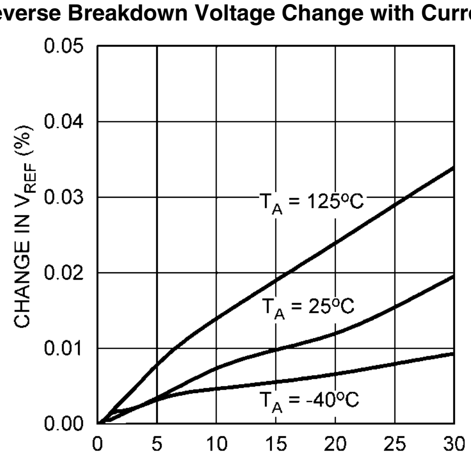
**Reverse Breakdown Voltage Change with Current**

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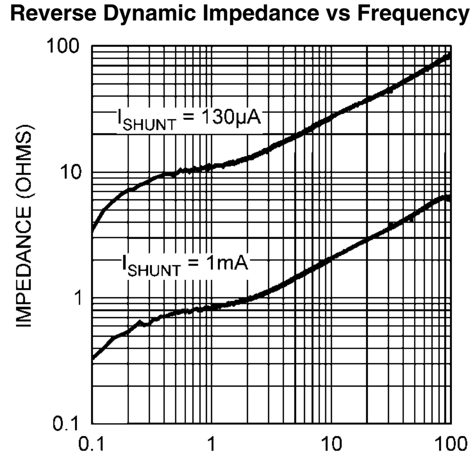
**Reverse Dynamic Impedance vs Frequency**

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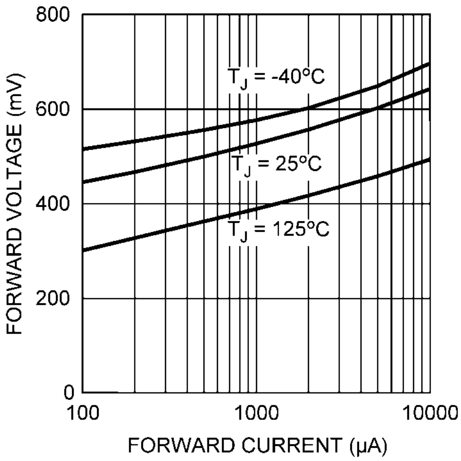
# Typical Performance Characteristics

**Forward Characteristic**

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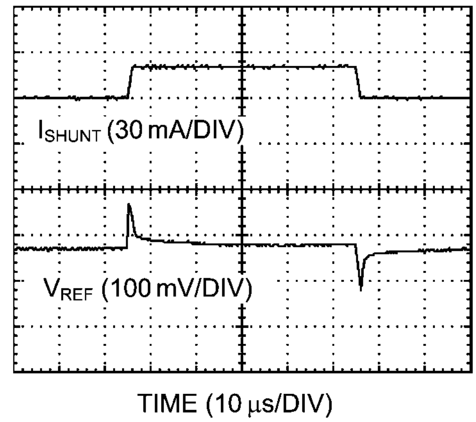
**Load Transient Response**

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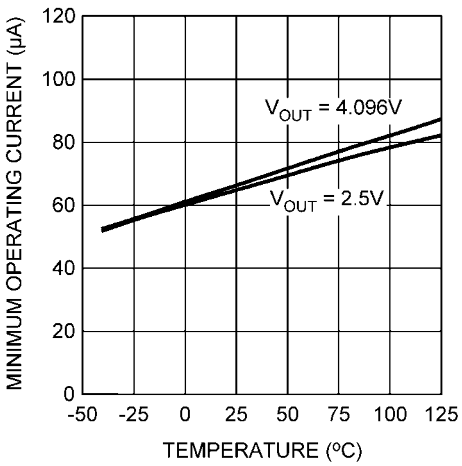
**Minimum Operating Current**

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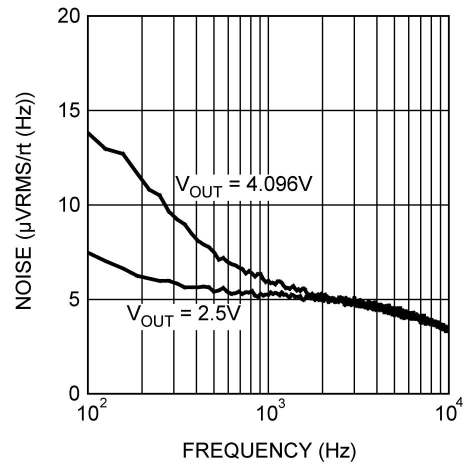
**Noise Spectrum**

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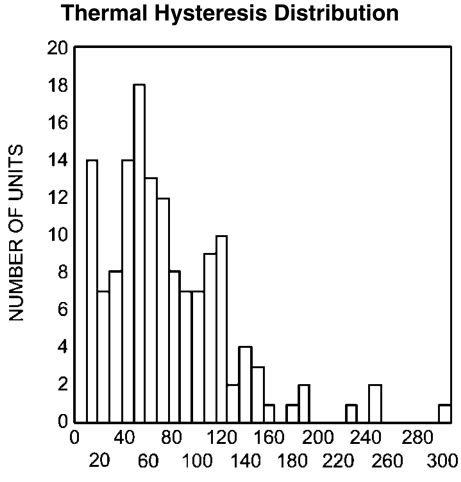
**Thermal Hysteresis Distribution**

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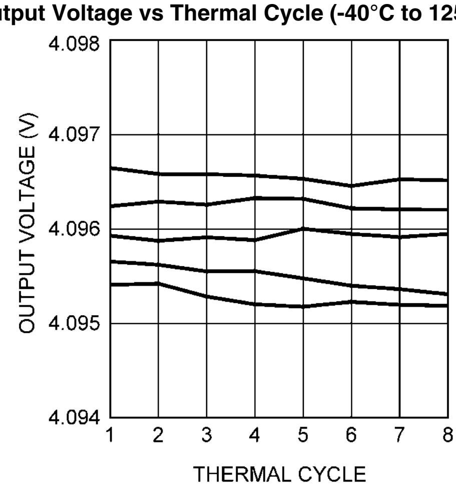
**Output Voltage vs Thermal Cycle (-40°C to 125°C)**

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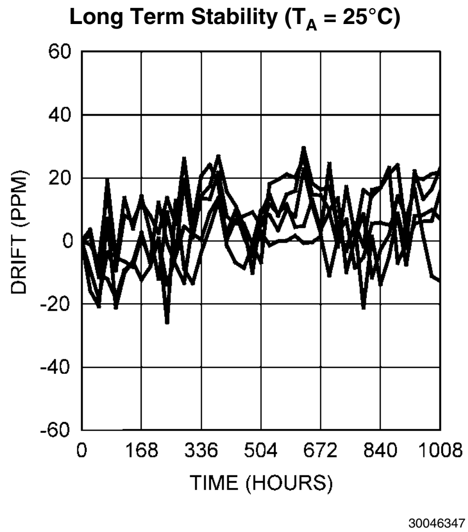
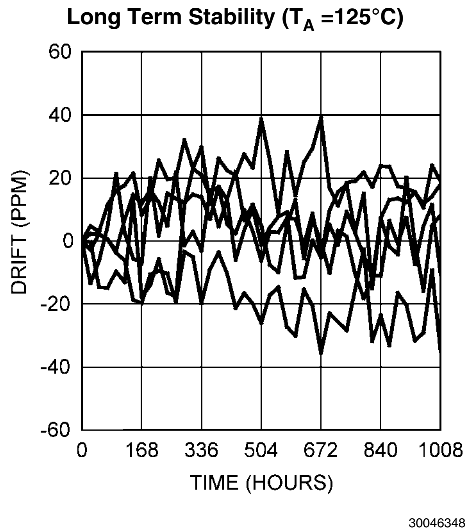

Long Term Stability ($T_A$ = 25°C)
60
40
20
0
-20
-40
-60
DRIFT (PPM)
0
168
336
504
672
840
1008
TIME (HOURS)
30046347


Long Term Stability ($T_A$ =125°C)
60
40
20
0
-20
-40
-60
DRIFT (PPM)
0
168
336
504
672
840
1008
TIME (HOURS)
30046348

# Application Information

### THEORY OF OPERATION

The LM4030 is an ultra-high precision shunt voltage reference, having exceptionally high initial accuracy (0.05%) and temperature stability (10ppm/°C). The LM4030 is available with fixed voltage options of 2.5V and 4.096V. Despite the tiny SOT23 package, the LM4030 exhibits excellent thermal hysteresis (75ppm) and long-term stability (25ppm). The LM4030 is designed to operate without an external capacitor, but any capacitor up to 10 µF may be used. The LM4030 can be powered off as little as 120 µA (max) but is capable of shunting up to 30 mA continuously. The typical application circuit for the LM4030 is shown in *Figure 1*.

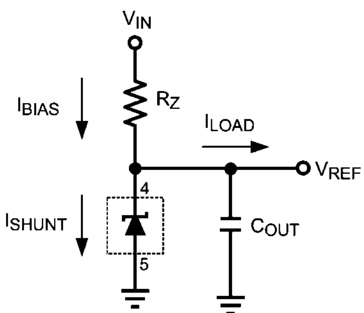



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**FIGURE 1. Typical Application Circuit**

### COMPONENT SELECTION

A resistor must be chosen to set the maximum operating current for the LM4030 ($R_Z$ in *Figure 1*). The value of the resistor can be calculated using the following equation:

$$R_Z = (V_{IN} - V_{REF})/(I_{MIN\_OPERATING} + I_{LOAD\_MAX})$$

$R_Z$ is chosen such that the total current flowing through $R_Z$ is greater than the maximum load current plus the minimum operating current of the reference itself. This ensures that the reference is never starved for current. Running the LM4030 at higher currents is advantageous for reducing noise. The reverse dynamic impedance of the $V_{REF}$ node scales inversely with the shunted current (see *Figure 2*) leading to higher rejection of noise emanating from the input supply and from EMI (electro-magnetic interferrence).

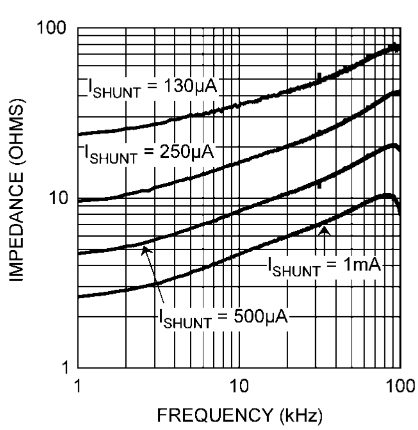


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**FIGURE 2. Reverse Dynamic Impedance vs $I_{OUT}$**

The LM4030 is designed to operate with or without a bypass capacitor ($C_{OUT}$ in *Figure 1*) and is stable with capacitors of up to 10 µF. The use of a bypass capacitor can improve transient response and reduce broadband noise. Additionally, a bypass capacitor will counter the rising reverse dynamic impedance at higher frequencies improving noise immunity (see *Figure 3*).

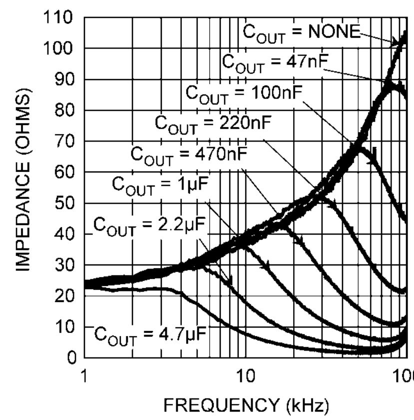


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**FIGURE 3. Reverse Dynamic Impedance vs $C_{OUT}$**

As with other regulators, an external capacitor reduces the amplitude of the $V_{REF}$ transient when a sudden change in loading takes place. The capacitor should be placed as close to the part as possible to reduce the effects of unwanted board parasitics.

### THERMAL HYSTERESIS

Thermal hysteresis is the defined as the change in output voltage at 25°C after some deviation from 25°C. This is to say that thermal hysteresis is the difference in output voltage between two points in a given temperature profile. An illustrative temperature profile is shown in *Figure 4*.

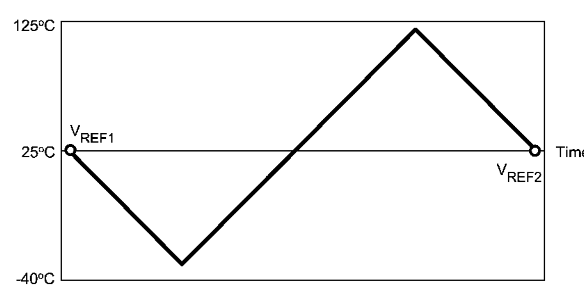


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**FIGURE 4. Illustrative Temperature Profile**

This may be expressed analytically as the following:

$$V_{HYS} = \frac{|V_{REF1} - V_{REF2}|}{V_{REF}} \times 10^6 \text{ ppm}$$

Where

$V_{HYS}$ = Thermal hysteresis expressed in ppm

$V_{REF}$ = Nominal preset output voltage

$V_{REF1}$ = $V_{REF}$ before temperature fluctuation

$V_{REF2} = V_{REF}$ after temperature fluctuation.

The LM4030 features a low thermal hysteresis of 75 ppm (typical) from -40°C to 125°C after 8 temperature cycles.

### TEMPERATURE COEFFICIENT

Temperature drift is defined as the maximum deviation in output voltage over the temperature range. This deviation over temperature may be illustrated as shown in *Figure 5*.

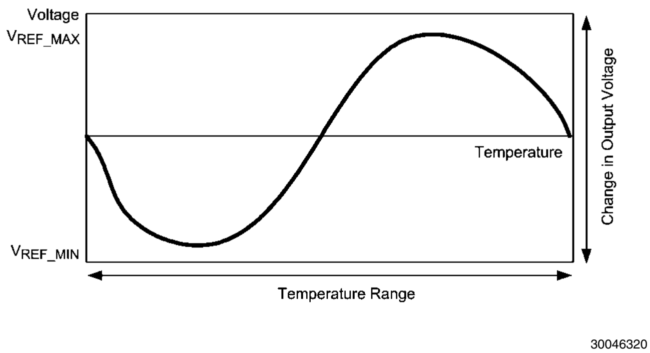



**FIGURE 5. Illustrative $V_{REF}$ vs Temperature Profile**

Temperature coefficient may be expressed analytically as the following:

$$T_D = \frac{(V_{REF\_MAX} - V_{REF\_MIN})}{V_{REF} \times \Delta T} \times 10^6 \text{ ppm}$$

$T_D$ = Temperature drift

$V_{REF}$ = Nominal preset output voltage

$V_{REF\_MIN}$ = Minimum output voltage over operating temperature range

$V_{REF\_MAX}$ = Maximum output voltage over operating temperature range

$\Delta T$ = Operating temperature range.

The LM4030 features a low temperature drift of 10ppm (max) to 30ppm (max), depending on the grade.

### DYNAMIC OFFSET CANCELLATION AND LONG TERM STABILITY

Aside from initial accuracy and drift performance, other specifications such as thermal hysteresis and long-term stability can affect the accuracy of a voltage reference, especially over the lifetime of the application. The reference voltage can also shift due to board stress once the part is mounted onto the PCB and during subsequent thermal cycles. Generally, these shifts in VREF arise due to offsets between matched devices within the regulation loop. Both passive and active devices naturally experience drift over time and stress and temperature gradients across the silicon die also generate offset. The LM4030 incorporates a dynamic offset cancellation scheme which compensates for offsets developing within the regulation loop. This gives the LM4030 excellent long-term stability (40 ppm typical) and thermal hysteresis performance (75ppm typical), as well as substantial immunity to PCB stress effects, despite being packaged in a tiny SOT23.

### EXPRESSION OF ELECTRICAL CHARACTERISTICS

Electrical characteristics are typically expressed in mV, ppm, or a percentage of the nominal value. Depending on the application, one expression may be more useful than the other. To convert one quantity to the other one may apply the following:

ppm to mV error in output voltage:

$$\frac{V_{REF} \times ppm_{ERROR}}{10^3} = V_{ERROR}$$

Where:

$V_{REF}$ is in volts (V) and $V_{ERROR}$ is in milli-volts (mV).

Bit error (1 bit) to voltage error (mV):

$$\frac{V_{REF}}{2^n} \times 10^3 = V_{ERROR}$$

$V_{REF}$ is in volts (V), $V_{ERROR}$ is in milli-volts (mV), and n is the number of bits.

mV to ppm error in output voltage:

$$\frac{V_{ERROR}}{V_{REF}} \times 10^3 = ppm_{ERROR}$$

Where:

$V_{REF}$ is in volts (V) and $V_{ERROR}$ is in milli-volts (mV).

Voltage error (mV) to percentage error (percent):

$$\frac{V_{ERROR}}{V_{REF}} \times 0.1 = Percent\_Error$$

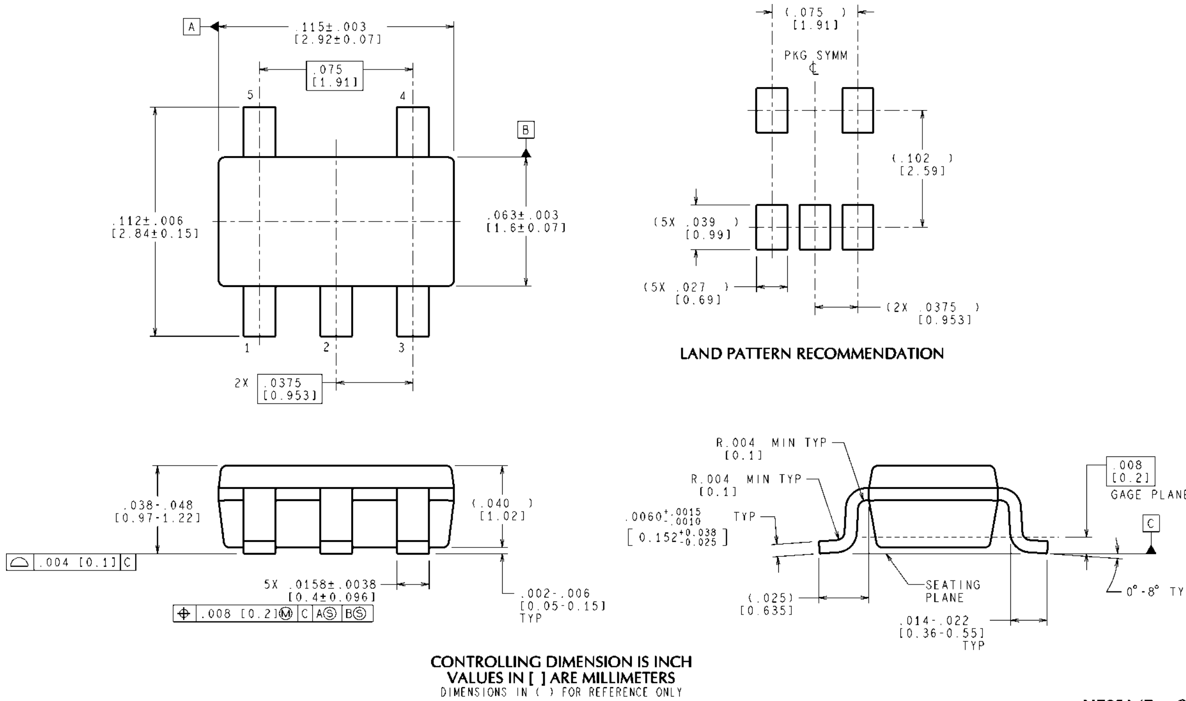
Where:

$V_{REF}$ is in volts (V) and $V_{ERROR}$ is in milli-volts (mV).

### PRINTED CIRCUIT BOARD and LAYOUT CONSIDERATIONS

The LM4030 has a very small change in reverse voltage with current (25ppm/mA typical) so large variations in load current (up to 50mA) should not appreciably shift VREF. Parasitic resistance between the LM4030 and the load introduces a voltage drop proportional to load current and should be minimized. The LM4030 should be placed as close to the load it is driving as the layout will allow. The location of $R_Z$ is not important, but $C_{OUT}$ should be as close to the LM4030 as possible so added ESR does not degrade the transient performance.

# Physical Dimensions inches (millimeters) unless otherwise noted




MF05A (Rev C)

**SOT23-5 Package**
**NS Package Number MF05A**

# Notes

# Notes

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