

LM4140

High Precision Low Noise Low Dropout Voltage Reference

General Description

The LM4140 series of precision references are designed to combine high accuracy, low drift and noise with low power dissipation in a small package.

The LM4140 is the industry's first reference with output voltage options lower than the bandgap voltage.

The key to the advance performance of the LM4140 is the use of EEPROM registers and CMOS DACs for temperature coefficient curvature correction and trimming of the output voltage accuracy of the device during the final production testing.

The major advantage of this method is the much higher resolution available with DACs than is available economically with most methods utilized by other bandgap references.

The low input and dropout voltage, low supply current and output drive capability of the LM4140 makes this product an ideal choice for battery powered and portable applications.

The LM4140 is available in three grades (A, B, C) with 0.1% initial accuracy and 3, 6 and 10 ppm/°C temperature coefficients. For even lower Tempco, contact National Semiconductor.

The device performance is specified over the temperature range (0°C to +70°C) and is available in compact 8-pin SO package.

For other output voltage options from 0.5V to 4.5V, contact National Semiconductor.

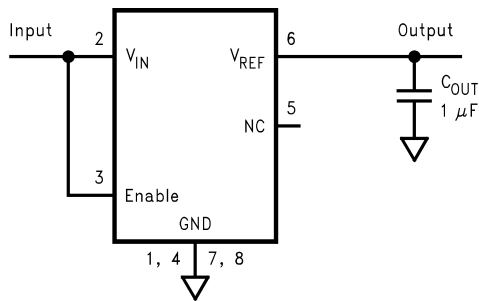
Features

- High initial accuracy: 0.1%
- Ultra low noise
- Low Temperature Coefficient: 3 ppm/°C (A grade)
- Low voltage operation: 1.8V
- SO-8 package
- Low dropout voltage: 20 mV (typ) @ 1mA
- Supply Current: 230 μ A (typ), \leq 1 μ A disable mode
- Enable pin
- Output voltage options: 1.024V, 1.250V, 2.048V, 2.500V, and 4.096V
- Custom voltages from 0.5V to 4.5V
- Temperature range (0°C to 70°C)

Applications Summary

- Portable, battery powered equipment
- Instrumentation and test equipment
- Automotive
- Industrial process control
- Data acquisition systems
- Medical equipment
- Precision scales
- Servo systems
- Battery charging

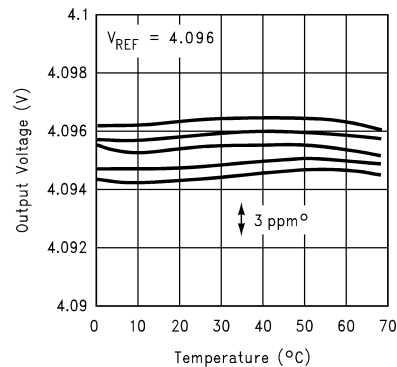
Typical Application



C_{OUT} , Output bypass capacitor. See text for selection detail.

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Typical Temperature Coefficient (Sample of 5 Parts)



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Refer to the Ordering Information Table in this Data Sheet for Specific Part Number

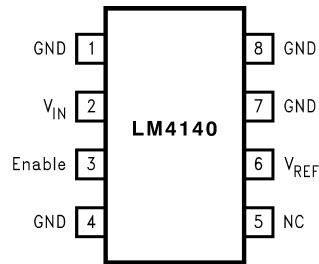
Ordering Information

Temperature Range
(0°C to 70°C)

Initial Output Voltage Accuracy @ 25°C and Temperature Coefficient	LM4140 Supplied as 95 Units, Tape and Reel	LM4140 Supplied as 2500 Units, Tape and Reel
0.1%, 3 ppm/°C max (A grade)	LM4140ACM-1.0	LM4140ACMX-1.0
	LM4140ACM-1.2	LM4140ACMX-1.2
	LM4140ACM-2.0	LM4140ACMX-2.0
	LM4140ACM-2.5	LM4140ACMX-2.5
	LM4140ACM-4.1	LM4140ACMX-4.1
0.1%, 6 ppm/°C max (B grade)	LM4140BCM-1.0	LM4140BCM-1.0
	LM4140BCM-1.2	LM4140BCM-1.2
	LM4140BCM-2.0	LM4140BCM-2.0
	LM4140BCM-2.5	LM4140BCM-2.5
	LM4140BCM-4.1	LM4140BCM-4.1
0.1%, 10 ppm/°C max (C grade)	LM4140CCM-1.0	LM4140CCMX-1.0
	LM4140CCM-1.2	LM4140CCMX-1.2
	LM4140CCM-2.0	LM4140CCMX-2.0
	LM4140CCM-2.5	LM4140CCMX-2.5
	LM4140CCM-4.1	LM4140CCMX-4.1

Connection Diagram

8-Lead Surface Mount (M)



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Top View
See NS Package Number M08A

Pin Functions

V_{ref} (Pin 6):	Reference Output. Capable of sourcing up to 8mA.
Input (Pin 2):	Positive Supply.
Ground (Pins 1, 4, 7, 8):	Negative Supply or Ground Connection. These pins must be connected to ground.
Enable (Pin 3):	Pulled to input for normal operation. Forcing this pin to ground will turn-off the output.
NC (Pin 5):	This pin must be left open.

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 pin	-0.3V to 5.6V
Output Short-Circuit Duration	Indefinite
Power Dissipation ($T_A = 25^\circ\text{C}$) (Note 2)	345mW
ESD Susceptibility (Note 3)	
Human Body Model	2 kV
Machine Model	200V

Lead Temperature:

Soldering, (10 sec.)

+260°C

Operating Range (Note 1)

Storage Temperature Range	-65°C to +150°C
Ambient Temperature Range	0°C to 70°C
Junction Temperature Range	0°C to 80°C

LM4140

Electrical Characteristics

Unless otherwise specified, $V_{IN} = 3.0\text{V}$ for the LM4140-1.024 and LM4140-1.250, $V_{IN} = 5.0\text{V}$ for all other voltage options, $V_{EN} = V_{IN}$, $C_{OUT} = 1\mu\text{F}$ (Note 4), $I_{LOAD} = 1\text{mA}$, $T_A = T_J = 25^\circ\text{C}$. Limits with standard typeface are for $T_A = 25^\circ\text{C}$, and limits in **bold type** apply over 0°C to 70°C temperature range.

Symbol	Parameter	Conditions	Min (Note 6)	Typ (Note 5)	Max (Note 6)	Units
V_{REF}	Output Voltage Initial Accuracy (Note 7)					
	LM4140B-1.024				±0.1	%
	LM4140B-1.250					
	LM4140B-2.048					
	LM4140B-2.500					
	LM4140B-4.096					
	LM4140C-1.024					
	LM4140C-1.250					
	LM4140C-2.048				±0.1	
	LM4140C-2.500					
LM4140C-4.096						
$TCV_{REF}/^\circ\text{C}$	Temperature Coefficient: A Grade B Grade C Grade	$0^\circ\text{C} \leq T_A \leq +70^\circ\text{C}$			3 6 10	ppm/°C
$\Delta V_{REF}/\Delta V_{IN}$	Line Regulation 1.024V and 1.250V options	$1.8\text{V} \leq V_{IN} \leq 5.5\text{V}$		50	300	ppm/V
	All other voltage options	$V_{ref} + 200\text{mV} \leq V_{IN} \leq 5.5\text{V}$		20	200 250	
$\Delta V_{REF}/\Delta I_{LOAD}$	Load Regulation All other voltage options	$1\text{mA} \leq I_{LOAD} \leq 8\text{mA}$		1	20	ppm/mA
	4.096V Option			5	35	
ΔV_{REF}	Long-Term Stability	1000 Hrs		60		ppm
ΔV_{REF}	Thermal Hysteresis (Note 8)	$0^\circ\text{C} \leq T_A \leq +70^\circ\text{C}$		20		ppm

LM4140**Electrical Characteristics** (Continued)

Unless otherwise specified, $V_{IN} = 3.0V$ for the LM4140-1.024 and LM4140-1.250, $V_{IN} = 5.0V$ for all other voltage options, $V_{EN} = V_{IN}$, $C_{OUT} = 1\mu F$ (Note 4), $I_{LOAD} = 1mA$, $T_A = T_J = 25^\circ C$. Limits with standard typeface are for $T_A = 25^\circ C$, and limits in **bold-face type** apply over $0^\circ C$ to $70^\circ C$ temperature range.

Symbol	Parameter	Conditions	Min (Note 6)	Typ (Note 5)	Max (Note 6)	Units
Operating Voltage	LM4140-1.024, LM4140-1.250	$I_L = 1\text{ mA to }8\text{ mA}$	1.8		5.5	V
$V_{IN}-V_{REF}$	Dropout Voltage (Note 9) LM4140-2.048, LM4140-2.500	$I_L = 1\text{ mA}$		20	40 45	mV
		$I_L = 8\text{ mA}$		160	235 400	
	LM4140-4.096	$I_L = 1\text{ mA}$		20	40 45	
		$I_L = 8\text{ mA}$		195	270 490	
V_N	Output Noise Voltage (Note 10)	0.1 Hz to 10 Hz		2.2		μV_{PP}
$I_{S(ON)}$	Supply Current All other voltage options	$I_{LOAD} = 0\text{ mA}$		230	320 375	μA
	4.096V Option			265	350 400	
$I_{S(OFF)}$	Supply Current	$V_{Enable} < 0.4V$.01	1	μA
V_H	Logic High Input Voltage		$0.8V_{IN}$			V
I_H	Logic High Input Current			2		nA
V_L	Logic Low Input Voltage				0.4	V
I_L	Logic Low Input Current			1		nA
I_{SC}	Short Circuit Current		8.5	20	35	mA
					40	

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

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), θ_{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. The θ_{J-A} for the SO-8 package is $160^\circ C/W$.

Note 3: The human body model is a 100 pF capacitor discharged through a 1.5 k Ω resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin.

Note 4: For proper operation, a 1 μF capacitor is required between the output pin and the GND pin of the device. (See Application Section for details)

Note 5: Typical numbers are at $25^\circ C$ and represent the most likely parametric norm.

Note 6: Limits are 100% production tested at $25^\circ C$. Limits over the operating temperature range are guaranteed through correlation using Statistical Quality Control (SQC) methods. The limits are used to calculate National's Average Outgoing Quality Level (AOQL).

Note 7: High temperature and mechanical stress associated with PCB assembly can have significant impact on the initial accuracy of the LM4140 and may create significant shifts in V_{REF} . See Application Hints section regarding accuracy and PCB layout consideration.

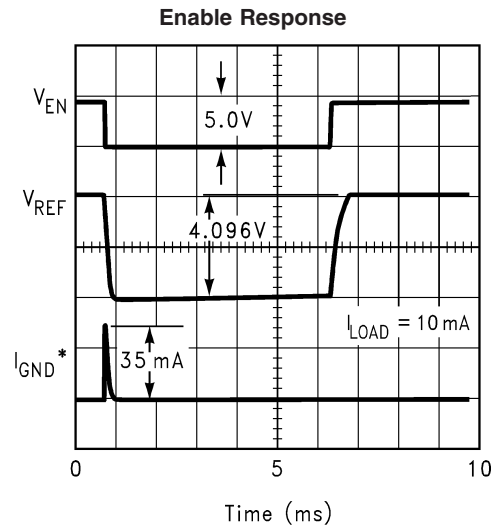
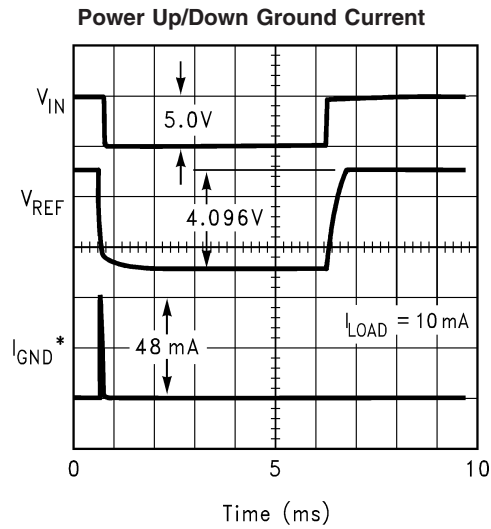
Note 8: Thermal hysteresis is defined as the changes in $+25^\circ C$ output voltage before and after the cycling of the device from $0^\circ C$ to $70^\circ C$.

Note 9: Dropout voltage is defined as the minimum input to output differential voltage at which the output voltage drops by 0.5% below the value measured with $V_{IN} = 3.0V$ for the LM4140-1.024 and LM4140-1.250, $V_{IN} = 5.0V$ for all other voltage options.

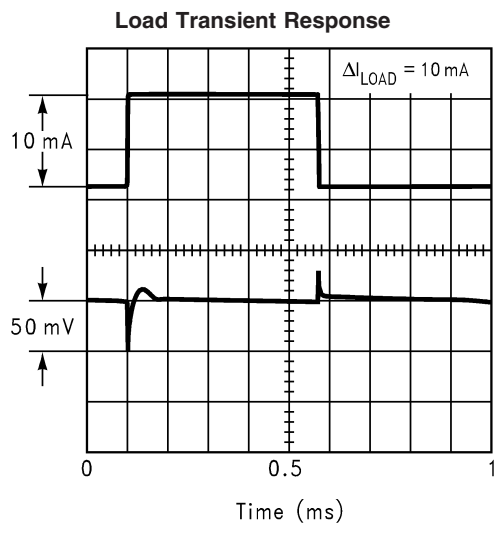
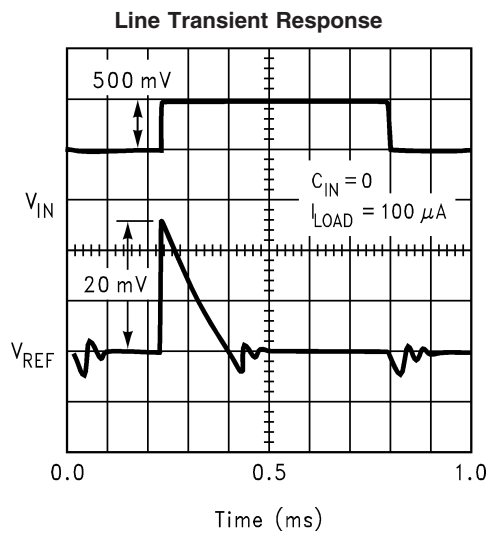
Note 10: The output noise is based on 1.024V option. Output noise is linearly proportional to V_{REF} .

LM4140 Typical Performance Characteristics

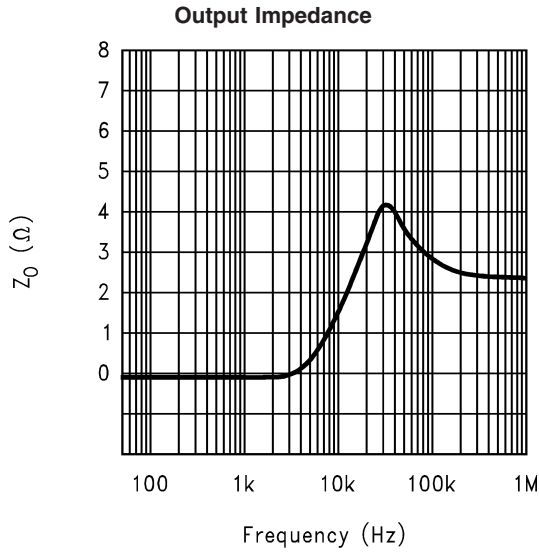
Unless otherwise specified, $T_A = 25^\circ\text{C}$, No Load, $C_{OUT} = 1\mu\text{F}$, $V_{IN} = 3.0\text{V}$ for LM4140-1.024 and LM4140-1.250, and 5V for all other voltage options. $V_{IN} = V_{EN}$.



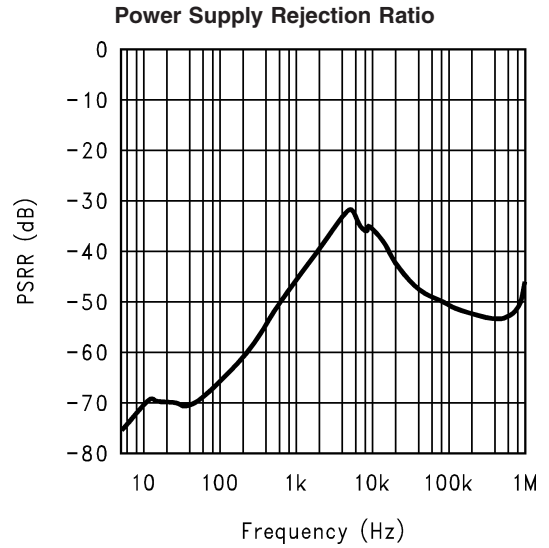
* The $1\mu\text{F}$ output capacitor is actively discharged to ground. See ON/OFF Operation section for more details.



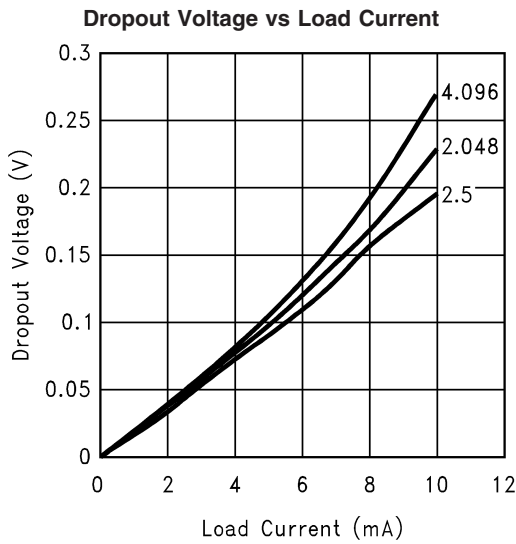
LM4140 Typical Performance Characteristics Unless otherwise specified, $T_A = 25^\circ\text{C}$, No Load, $C_{OUT} = 1\mu\text{F}$, $V_{IN} = 3.0\text{V}$ for LM4140-1.024 and LM4140-1.250, and 5V for all other voltage options. $V_{IN} = V_{EN}$. (Continued)



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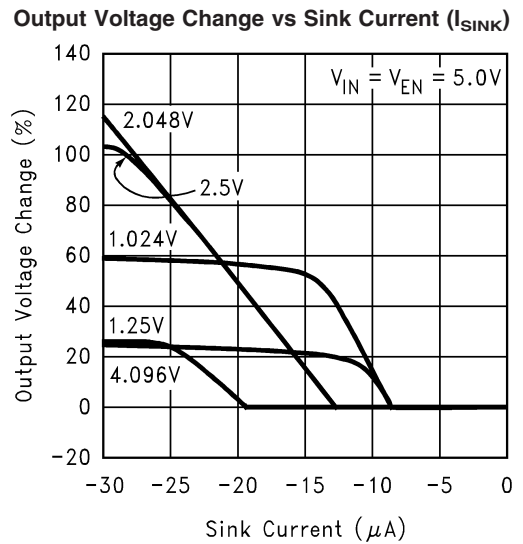


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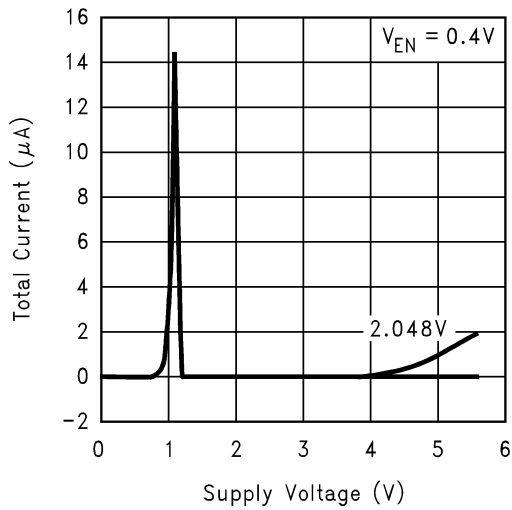
Note: 1.024V and 1.250V options require 1.8V supply.



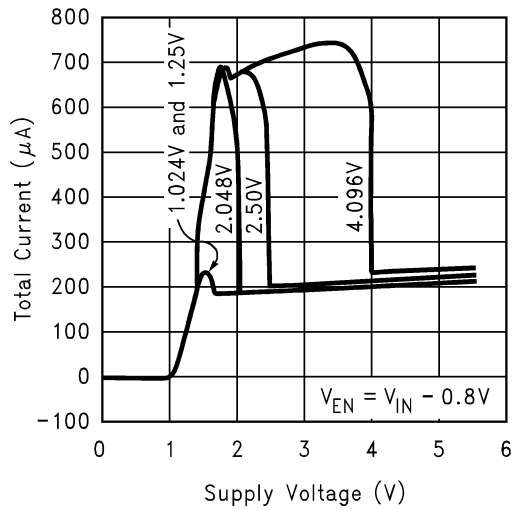
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LM4140 Typical Performance Characteristics Unless otherwise specified, $T_A = 25^\circ\text{C}$, No Load, $C_{OUT} = 1\mu\text{F}$, $V_{IN} = 3.0\text{V}$ for LM4140-1.024 and LM4140-1.250, and 5V for all other voltage options. $V_{IN} = V_{EN}$. (Continued)

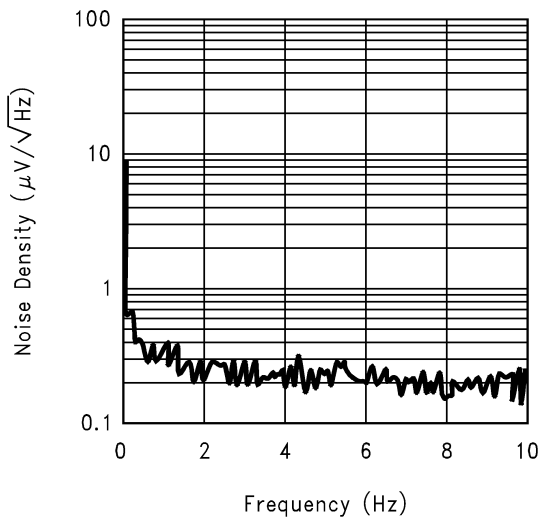
Total Current ($I_{S(OFF)}$) vs Supply Voltage



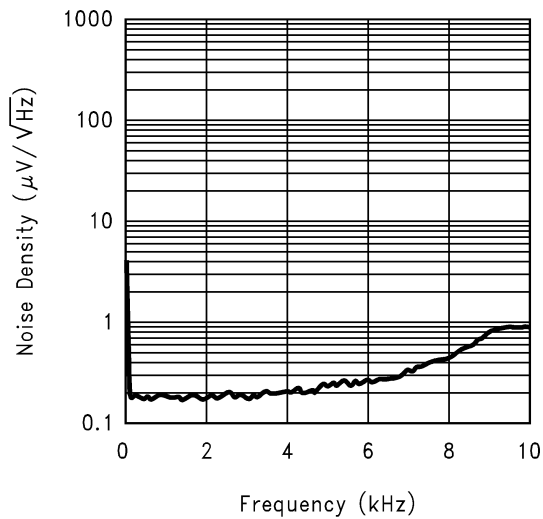
Total Current ($I_{S(ON)}$) vs Supply Voltage



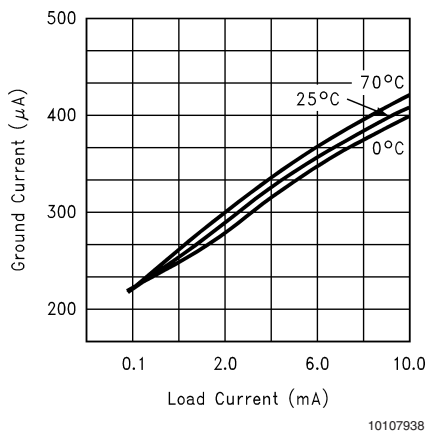
Spectral Noise Density (0.1Hz to 10Hz)



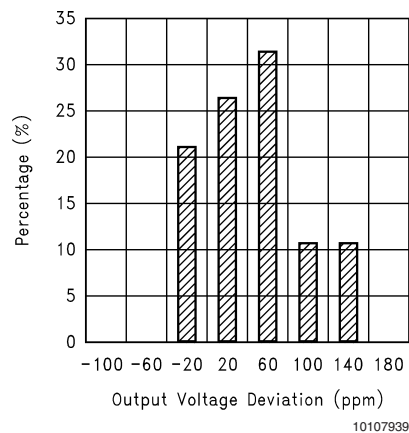
Spectral Noise Density (10Hz to 100kHz)



Ground Current vs Load Current

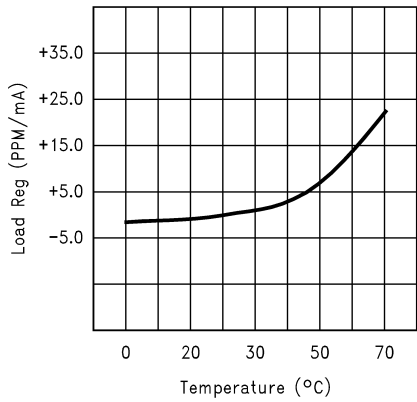


Long Term Drift



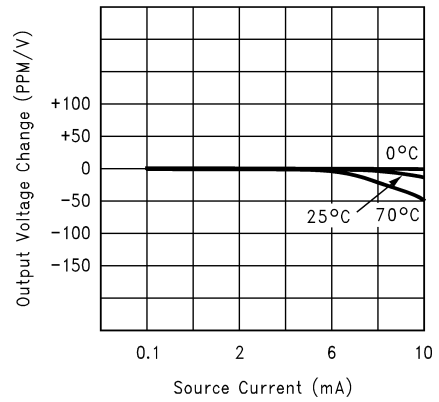
LM4140 Typical Performance Characteristics Unless otherwise specified, $T_A = 25^\circ\text{C}$, No Load, $C_{OUT} = 1\mu\text{F}$, $V_{IN} = 3.0\text{V}$ for LM4140-1.024 and LM4140-1.250, and 5V for all other voltage options. $V_{IN} = V_{EN}$. (Continued)

Load Regulation vs Temperature



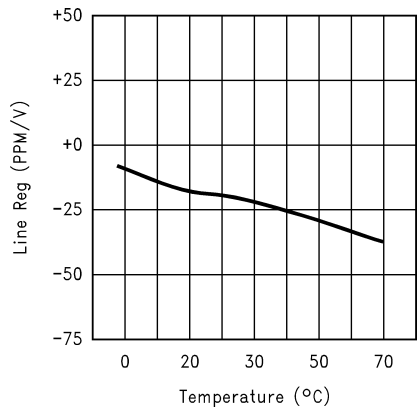
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Output Voltage vs Load Current



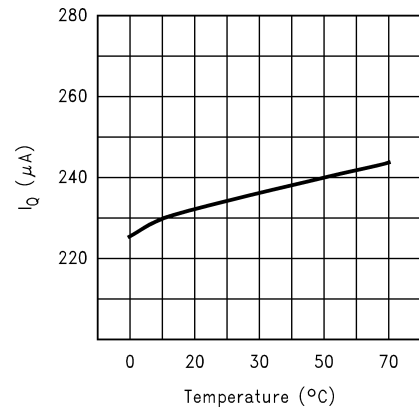
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Line Regulation vs Temperature



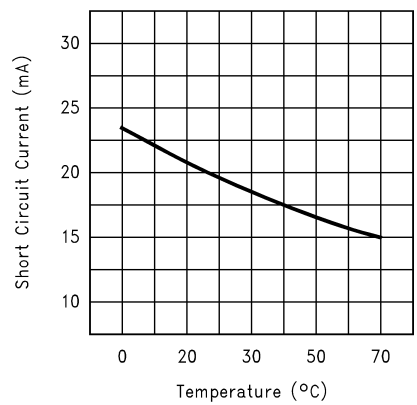
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I_Q vs Temperature



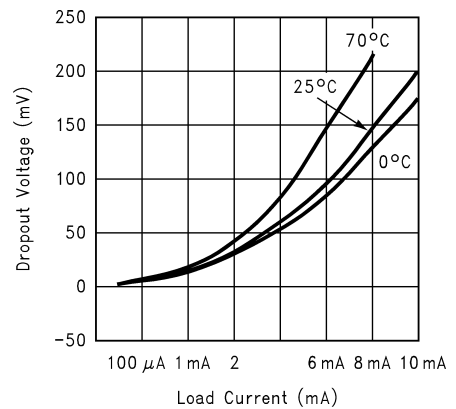
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Short Circuit Current vs Temperature



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Dropout Voltage vs Load Current ($V_{OUT} = 2.0\text{V}$)



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Application Hints

INPUT CAPACITORS

Although not always required, an input capacitor is recommended. A supply bypass capacitor on the input assures that the reference is working from a source with low impedance, which improves stability. A bypass capacitor can also improve transient response by providing a reservoir of stored energy that the reference can utilize in case where the load current demand suddenly increases. The value used for C_{IN} may be used without limit. Refer to the typical application section for examples of input capacitors.

OUTPUT CAPACITORS

The LM4140 requires a $1\mu\text{F}$ (nominally) output capacitor for loop stability (compensation) as well as transient response. During the sudden changes in load current demand, the output capacitor must source or sink current during the time it takes the control loop of the LM4140 to respond.

This capacitor must be selected to meet the requirements of minimum capacitance and equivalent series resistance (ESR) range.

In general, the capacitor value must be at least $0.2\mu\text{F}$ (over the actual ambient operating temperature), and the ESR must be within the range indicated in *Figure 1*, *Figure 2* and *Figure 3*.

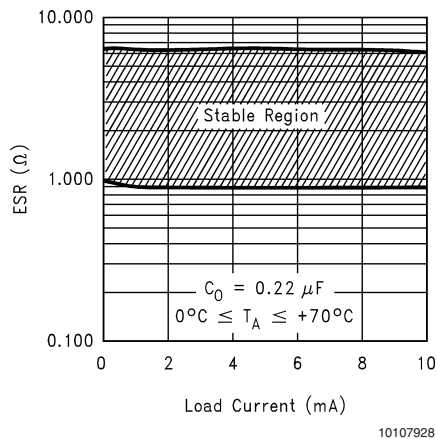


FIGURE 1. 0.22 μF ESR Range

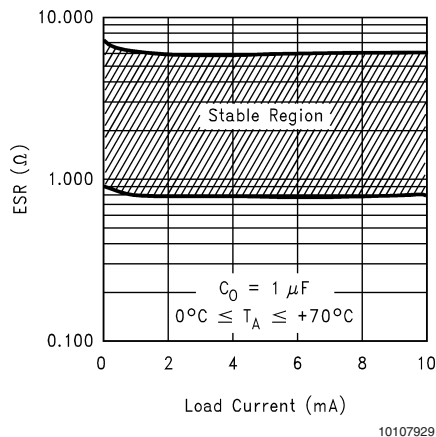


FIGURE 2. 1 μF ESR Range

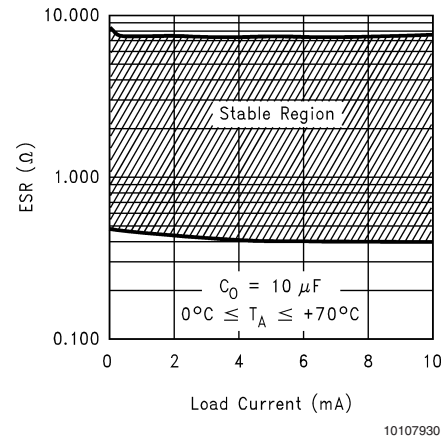


FIGURE 3. 10 μF ESR Range

TANTALUM CAPACITORS

Surface-mountable solid tantalum capacitors offer a good combination of small physical size for the capacitance value, and ESR in the range needed for by the LM4140. The results of testing the LM4140 stability with surface mount solid tantalum capacitors show good stability with values in the range of $0.1\mu\text{F}$. However, optimum performance is achieved with a $1\mu\text{F}$ capacitor.

Tantalum capacitors that have been verified as suitable for use with the LM4140 are shown in *Table 1*.

TABLE 1. Surface-Mount Tantalum Capacitor Selection Guide

1 μF Surface-Mount Tantalums	
Manufacturer	Part Number
Kemet	T491A105M010AS
NEC	NRU105N10
Siemens	B45196-E3105-K
Nichicon	F931C105MA
Sprague	293D105X0016A2T
2.2 μF Surface-Mount Tantalums	
Kemet	T491A225M010AS
NEC	NRU225M06
Siemens	B45196/2.2/10/10
Nichicon	F930J225MA
Sprague	293D225X0010A2T

ALUMINUM ELECTROLYTIC CAPACITORS

Although probably not a good choice for a production design, because of relatively large physical size, an aluminium electrolytic capacitor can be used in the design prototype for an LM4140 reference. A $1\mu\text{F}$ capacitor meeting the ESR conditions can be used. If the operating temperature drops below 0°C , the reference may not remain stable, as the ESR of the aluminium electrolytic capacitor will increase, and may exceed the limits indicated in the figures.

Application Hints (Continued)

MULTILAYER CERAMIC CAPACITORS

Surface-mountable multilayer ceramic capacitors may be an attractive choice because of their relatively small physical size and excellent RF characteristics.

However, they sometimes have an ESR values lower than the minimum required by the LM4140, and relatively large capacitance change with temperature. The manufacturer's datasheet for the capacitor should be consulted before selecting a value. Test results of LM4140 stability using multilayer ceramic capacitors show that a minimum of 0.2 μ F is usually needed.

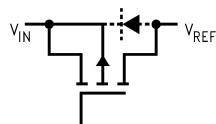
Multilayer ceramic capacitors that have been verified as suitable for use with the LM4140 are shown in *Table 2*.

TABLE 2. Surface-Mount Ceramic Capacitors Selection Guide

2.2 μ F Surface-Mount Ceramic	
Manufacturer	Part Number
Tokin	1E225ZY5U-C203
Murata	GRM42-6Y5V225Z16
4.7 μ F Surface-Mount Ceramic	
Tokin	1E475ZY5U-C304

REVERSE CURRENT PATH

The P-channel Pass transistor used in the LM4140 has an inherent diode connected between the V_{IN} and V_{REF} pins (see diagram below).



Forcing the output to voltages higher than the input, or pulling V_{IN} below voltage stored on the output capacitor by more than a V_{be} , will forward bias this diode and current will flow from the V_{REF} terminal to V_{IN} . No damage to the LM4140 will occur under these conditions as long as the current flowing into the output pin does not exceed 50mA.

ON/OFF OPERATION

The LM4140 is designed to quickly reduce both V_{REF} and I_Q to zero when turned-off. V_{REF} is restored in less than 200 μ s when turned-on. During the turn-off, the charge across the output capacitor is discharged to ground through internal circuitry.

The LM4140 is turned-off by pulling the enable input low, and turned-on by driving the input high. If this feature is not to be used, the enable pin should be tied to the V_{IN} to keep the reference on at all times (the enable pin must not be left floating).

To ensure proper operation, the signal source used to drive the enable pin must be able to swing above and below the specified high and low voltage thresholds which guarantee an ON or OFF state (see Electrical Characteristics).

The ON/OFF signal may come from either a totem-pole output, or an open-collector output with pull-up resistor to the LM4140 input voltage. This high-level voltage may exceed

the LM4140 input voltage, but must remain within the Absolute Maximum Rating for the enable pin.

OUTPUT ACCURACY

Like all references, either series or shunt, the after assembly accuracy is made up of primarily three components: initial accuracy itself, thermal hysteresis and effects of the PCB assembly stress.

LM4140 provides an excellent output initial accuracy of 0.1% and temperature coefficient of 6ppm/ $^{\circ}$ C (B Grade).

For best accuracy and precision, the LM4140 junction temperature should not exceed 70 $^{\circ}$ C.

The thermal hysteresis curve on this datasheet are performance characteristics of three typical parts selected at random from a sample of 40 parts.

Parts are mounted in a socket to minimize the effect of PCB's mechanical expansion and contraction. Readings are taken at 25 $^{\circ}$ C following multiple temperature cycles to 0 $^{\circ}$ C and 70 $^{\circ}$ C. The labels on the X axis of the graph indicates the device temperature cycle prior to measurement at 25 $^{\circ}$ C.

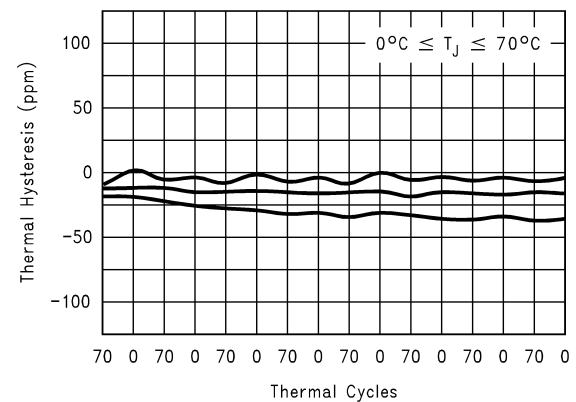


FIGURE 4. Typical Thermal Hysteresis

The mechanical stress due to the PCB's mechanical and thermal stress can cause an output voltage shift more than the true thermal coefficient of the device. References in surface mount packages are more susceptible to these stresses because of the small amount of plastic molding which support the leads.

Following the recommendations on **PCB Layout Consideration** section can minimize the mechanical stress on the device.

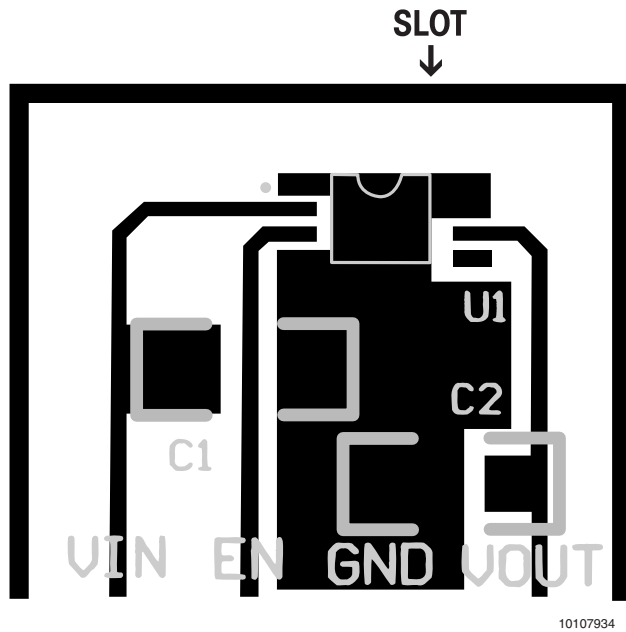
PCB LAYOUT CONSIDERATION

The simplest ways to reduce the stress related shifts are:

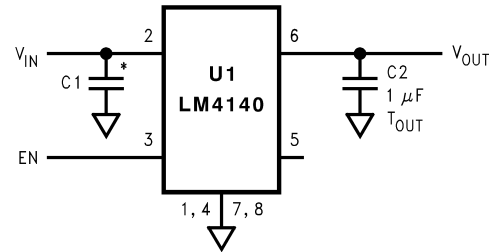
1. Mounting the device near the edges or the corners of the board where mechanical stress is at its minimum. The center of the board generally has the highest mechanical and thermal expansion stress.
2. Mechanical isolation of the device by creating an island by cutting a U shape slot on the PCB for mounting the device. This approach would also provide some thermal isolation from the rest of the circuit.

Figure 5 is a recommended printed board layout with a slot cut on three sides of the circuit layout to serve as a strain relief.

Application Hints (Continued)



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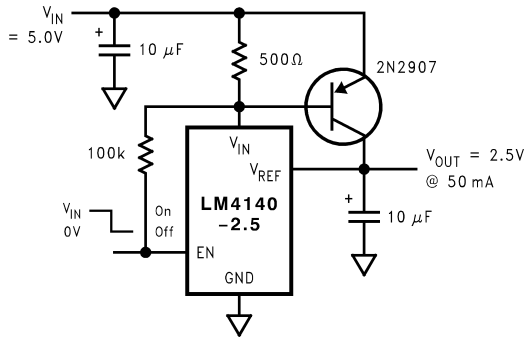
* Optional input Capacitor ($0.1 \mu\text{F}$ or higher).

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FIGURE 5. Suggested PCB Layout with Slot

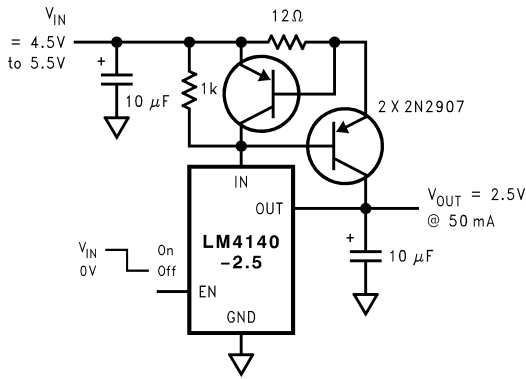
Typical Application Circuits

Boosted Output Current



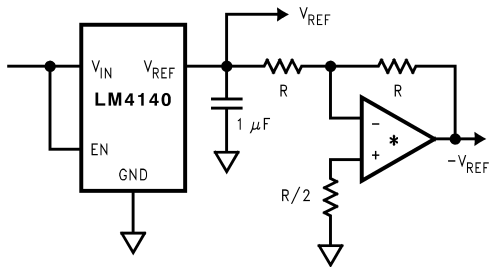
10107915

Boosted Output Current with Current Limiter



10107922

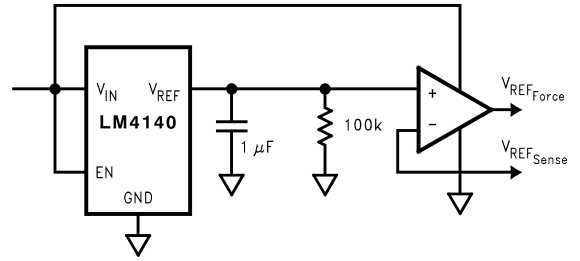
Complimentary Outputs



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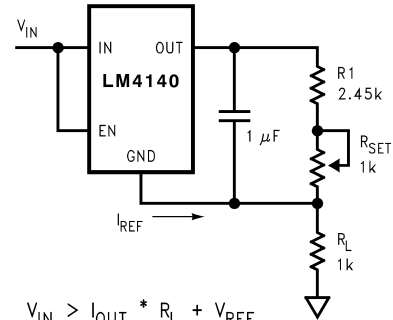
* Low Noise Op Amp such as OP-27

Voltage Reference with Force and Sense Output



10107920

Precision Programmable Current Source



$$V_{IN} > I_{OUT} * R_L + V_{REF}$$

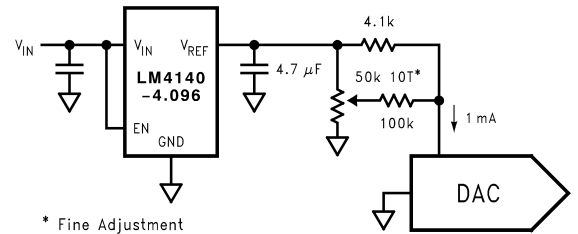
$$I_{OUT} = (V_{REF} / (R_1 + R_{SET})) + I_{REF}$$

$$R_1 = 2.45k \text{ for}$$

$$I_L = 1 \text{ mA using LM4120-2.5}$$

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Precision DAC Reference

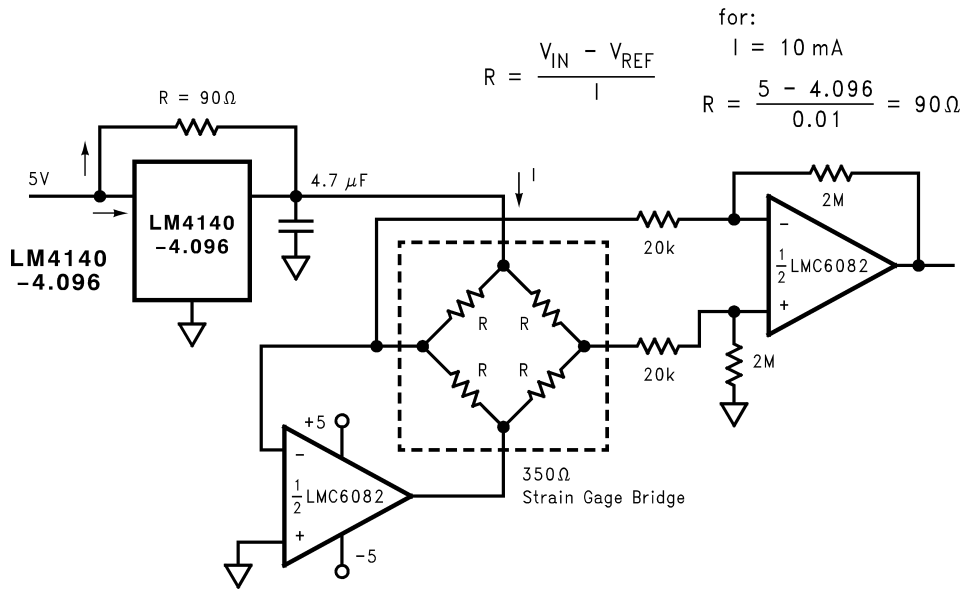


* Fine Adjustment

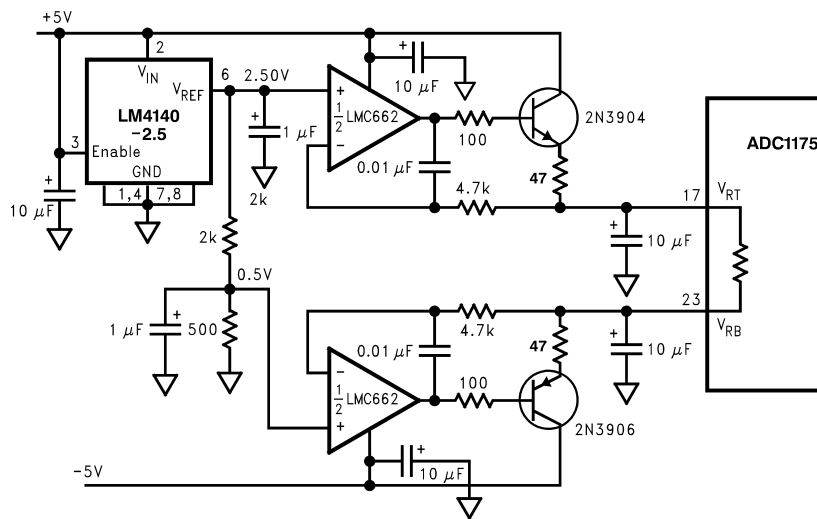
10107936

Typical Application Circuits (Continued)

Strain Gauge Conditioner for 350Ω Bridge



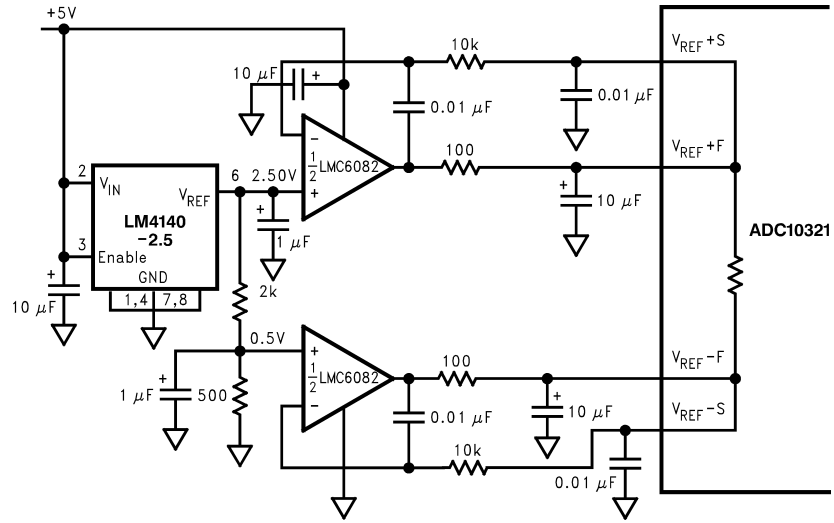
10107937



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FIGURE 6.

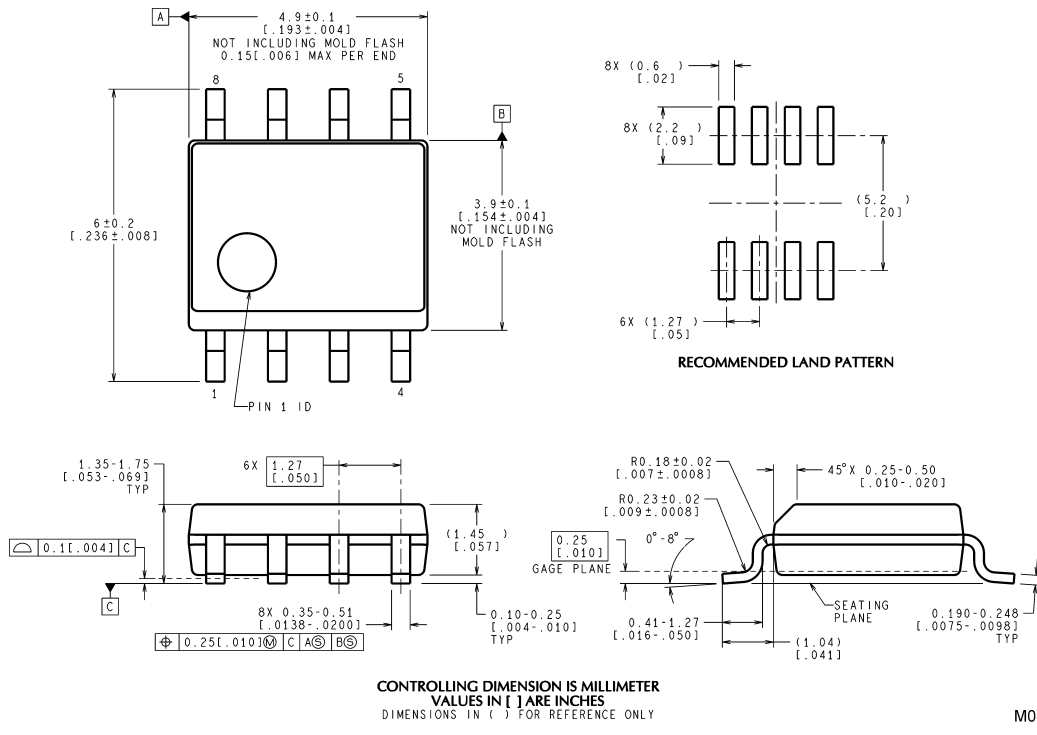
Typical Application Circuits (Continued)



10107927

FIGURE 7.

Physical Dimensions inches (millimeters) unless otherwise noted



M08A (Rev K)

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