

## LM9140 Precision Micropower Shunt Voltage Reference

### General Description

The LM9140's reverse breakdown voltage temperature coefficients of  $\pm 25$  ppm/ $^{\circ}$ C are ideal for precision applications. The LM9140's advanced design eliminates the need for an external stabilizing capacitor while ensuring stability with any capacitive load, thus making the LM9140 easy to use. Further reducing design effort is the availability of several fixed reverse breakdown voltages: 2.500V, 4.096V, 5.000V, and 10.000V. The minimum operating current increases from 60  $\mu$ A for the LM9140-2.5 to 100  $\mu$ A for the LM9140-10.0. All versions have a maximum operating current of 15 mA.

The LM9140 utilizes fuse and zener-zap reverse breakdown voltage trim during wafer sort to ensure that the prime parts have an accuracy of better than  $\pm 0.5\%$  (B grade) at 25 $^{\circ}$ C. Bandgap reference temperature drift curvature correction and low dynamic impedance ensure stable reverse breakdown voltage accuracy over a wide range of operating temperatures and currents.

### Features

- Guaranteed temperature coefficient of  $\pm 25$  ppm/ $^{\circ}$ C
- Reverse breakdown voltage tolerance of  $\pm 0.5\%$
- Small package: TO-92
- No output capacitor required

- Tolerates capacitive loads
- Fixed reverse breakdown voltages of 2.500V, 4.096V, 5.000V, and 10.000V

### Key Specifications

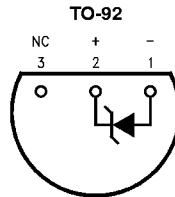
(LM9140-2.5)

- Temperature coefficient:  $\pm 25$  ppm/ $^{\circ}$ C (max)
- Output voltage tolerance:  $\pm 0.5\%$  (max)
- Low output noise (10 Hz to 10 kHz): 35  $\mu$ V<sub>rms</sub> (typ)
- Wide operating current range: 60  $\mu$ A to 15 mA
- Industrial temperature range: -40 $^{\circ}$ C to +85 $^{\circ}$ C

### Applications

- Portable, Battery-Powered Equipment
- Data Acquisition Systems
- Instrumentation
- Process Control
- Energy Management
- Product Testing
- Automotive
- Precision Audio Components

### Connection Diagram



DS011393-2

**Bottom View**  
See NS Package Number Z03A

### Ordering Information

Reverse Breakdown Voltage Tolerance at 25 $^{\circ}$ C and Average Reverse Breakdown Voltage Temperature Coefficient	Z (TO-92)
0.5%, 25 ppm/ $^{\circ}$ C max	LM9140BYZ-2.5, LM9140BYZ-4.1, LM9140BYZ-5.0, LM9140BYZ-10.0

### Absolute Maximum Ratings (Note 1)

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

Reverse Current	20 mA
Forward Current	10 mA
Power Dissipation ( $T_A = 25^\circ\text{C}$ ) (Note 2)	
Z Package	550 mW
Storage Temperature	$-65^\circ\text{C}$ to $+150^\circ\text{C}$
Lead Temperature	
Z Package	
Soldering (10 seconds)	$+260^\circ\text{C}$
ESD Susceptibility	

Human Boddy Mode (Note 3)	2 kV
Machine Model (Note 3)	200V

### Operating Ratings (Notes 1, 2)

Temperature Range ( $T_{\min} \leq T_A \leq T_{\max}$ )	$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$
Reverse Current	
LM9140-2.5	60 $\mu\text{A}$ to 15 mA
LM9140-4.1	68 $\mu\text{A}$ to 15 mA
LM9140-5.0	74 $\mu\text{A}$ to 15 mA
LM9140-10.0	100 $\mu\text{A}$ to 15 mA

## LM9140BYZ-2.5

### Electrical Characteristics

**Boldface limits apply for  $T_A = T_J = T_{\min}$  to  $T_{\max}$ ; all other limits  $T_A = T_J = 25^\circ\text{C}$**

Symbol	Parameter	Conditions	Typical (Note 4)	Limits (Note 5)	Units (Limit)
$V_R$	Reverse Breakdown Voltage	$I_R = 100 \mu\text{A}$	2.500		V
	Reverse Breakdown Voltage Tolerance (Note 6)	$I_R = 100 \mu\text{A}$		$\pm 12.5$ <b><math>\pm 16.6</math></b>	mV (max) mV (max)
$I_{R\min}$	Minimum Operating Current		45	60 <b>65</b>	$\mu\text{A}$ $\mu\text{A}$ (max) $\mu\text{A}$ (max)
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient (Note 7)	$I_R = 10 \text{ mA}$	$\pm 10$		ppm/ $^\circ\text{C}$
		$I_R = 1 \text{ mA}$	$\pm 10$	<b><math>\pm 25</math></b>	ppm/ $^\circ\text{C}$ (max)
		$I_R = 100 \mu\text{A}$	$\pm 10$		ppm/ $^\circ\text{C}$
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{R\min} \leq I_R \leq 1 \text{ mA}$	0.3	0.8 <b>1.0</b>	mV mV (max) mV (max)
		$1 \text{ mA} \leq I_R \leq 15 \text{ mA}$	2.5	6.0 <b>8.0</b>	mV mV (max) mV (max)
$Z_R$	Reverse Dynamic Impedance	$I_R = 1 \text{ mA}$ , $f = 120 \text{ Hz}$ , $I_{AC} = 0.1 I_R$	0.3	0.8	$\Omega$ $\Omega$ (max)
$e_N$	Wideband Noise	$I_R = 100 \mu\text{A}$ $10 \text{ Hz} \leq f \leq 10 \text{ kHz}$	35		$\mu\text{V}_{\text{rms}}$
$\Delta V_R$	Reverse Breakdown Voltage Long Term Stability	$t = 1000 \text{ hrs}$ $T = 25^\circ\text{C} \pm 0.1^\circ\text{C}$ $I_R = 100 \mu\text{A}$	120		ppm

## LM9140BYZ-4.1

### Electrical Characteristics

**Boldface limits apply for  $T_A = T_J = T_{\min}$  to  $T_{\max}$ ; all other limits  $T_A = T_J = 25^\circ\text{C}$**

Symbol	Parameter	Conditions	Typical (Note 4)	Limits (Note 5)	Units (Limit)
$V_R$	Reverse Breakdown Voltage	$I_R = 100 \mu\text{A}$	4.096		V
	Reverse Breakdown Voltage Tolerance (Note 6)	$I_R = 100 \mu\text{A}$		$\pm 20.5$ <b><math>\pm 27.1</math></b>	mV (max) mV (max)

## Electrical Characteristics (Continued)

**Boldface limits apply for  $T_A = T_J = T_{MIN}$  to  $T_{MAX}$ ; all other limits  $T_A = T_J = 25^\circ\text{C}$**

Symbol	Parameter	Conditions	Typical (Note 4)	Limits (Note 5)	Units (Limit)
$I_{RMIN}$	Minimum Operating Current		50	68 <b>73</b>	$\mu\text{A}$ $\mu\text{A (max)}$ $\mu\text{A (max)}$
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient (Note 7)	$I_R = 10\text{ mA}$ $I_R = 1\text{ mA}$ $I_R = 100\ \mu\text{A}$	$\pm 10$ $\pm 10$ $\pm 10$	<b><math>\pm 25</math></b>	ppm/ $^\circ\text{C}$ ppm/ $^\circ\text{C (max)}$ ppm/ $^\circ\text{C}$
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{RMIN} \leq I_R \leq 1\text{ mA}$	0.5	0.9 <b>1.2</b>	mV mV (max) mV (max)
		$1\text{ mA} \leq I_R \leq 15\text{ mA}$	3.0	7.0 <b>10.0</b>	mV mV (max) mV (max)
$Z_R$	Reverse Dynamic Impedance	$I_R = 1\text{ mA}$ , $f = 120\text{ Hz}$ , $I_{AC} = 0.1 I_R$	0.5	1.0	$\Omega$ $\Omega(\text{max})$
$e_N$	Wideband Noise	$I_R = 100\ \mu\text{A}$ $10\text{ Hz} \leq f \leq 10\text{ kHz}$	80		$\mu\text{V}_{\text{rms}}$
$\Delta V_R$	Reverse Breakdown Voltage Long Term Stability	$t = 1000\text{ hrs}$ $T = 25^\circ\text{C} \pm 0.1^\circ\text{C}$ $I_R = 100\ \mu\text{A}$	120		ppm

## LM9140BYZ-5.0

### Electrical Characteristics

**Boldface limits apply for  $T_A = T_J = T_{MIN}$  to  $T_{MAX}$ ; all other limits  $T_A = T_J = 25^\circ\text{C}$**

Symbol	Parameter	Conditions	Typical (Note 4)	Limits (Note 5)	Units (Limit)
$V_R$	Reverse Breakdown Voltage	$I_R = 100\ \mu\text{A}$	5.000		V
	Reverse Breakdown Voltage Tolerance (Note 6)	$I_R = 100\ \mu\text{A}$		$\pm 25.0$ <b><math>\pm 33.1</math></b>	mV (max) mV (max)
$I_{RMIN}$	Minimum Operating Current		55	74 <b>80</b>	$\mu\text{A}$ $\mu\text{A (max)}$ $\mu\text{A (max)}$
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient (Note 7)	$I_R = 10\text{ mA}$ $I_R = 1\text{ mA}$ $I_R = 100\ \mu\text{A}$	$\pm 10$ $\pm 10$ $\pm 10$	<b><math>\pm 25</math></b>	ppm/ $^\circ\text{C}$ ppm/ $^\circ\text{C (max)}$ ppm/ $^\circ\text{C}$
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{RMIN} \leq I_R \leq 1\text{ mA}$	0.5	1.0 <b>1.4</b>	mV mV (max) mV (max)
		$1\text{ mA} \leq I_R \leq 15\text{ mA}$	3.5	8.0 <b>12.0</b>	mV mV (max) mV (max)
$Z_R$	Reverse Dynamic Impedance	$I_R = 1\text{ mA}$ , $f = 120\text{ Hz}$ , $I_{AC} = 0.1 I_R$	0.5	1.1	$\Omega$ $\Omega(\text{max})$
$e_N$	Wideband Noise	$I_R = 100\ \mu\text{A}$ $10\text{ Hz} \leq f \leq 10\text{ kHz}$	80		$\mu\text{V}_{\text{rms}}$

## Electrical Characteristics (Continued)

**Boldface limits apply for  $T_A = T_J = T_{MIN}$  to  $T_{MAX}$ ; all other limits  $T_A = T_J = 25^\circ\text{C}$**

Symbol	Parameter	Conditions	Typical (Note 4)	Limits (Note 5)	Units (Limit)
$\Delta V_R$	Reverse Breakdown Voltage Long Term Stability	$t = 1000$ hrs $T = 25^\circ\text{C} \pm 0.1^\circ\text{C}$ $I_R = 100 \mu\text{A}$	120		ppm

## LM9140BYZ-10.0

### Electrical Characteristics

**Boldface limits apply for  $T_A = T_J = T_{MIN}$  to  $T_{MAX}$ ; all other limits  $T_A = T_J = 25^\circ\text{C}$**

Symbol	Parameter	Conditions	Typical (Note 4)	Limits (Note 5)	Units (Limit)
$V_R$	Reverse Breakdown Voltage	$I_R = 150 \mu\text{A}$	10.00		V
	Reverse Breakdown Voltage Tolerance (Note 6)	$I_R = 100 \mu\text{A}$		$\pm 50.0$ <b><math>\pm 66.3</math></b>	mV (max) mV (max)
$I_{RMIN}$	Minimum Operating Current		75	100	$\mu\text{A}$
				<b>103</b>	$\mu\text{A}$ (max) $\mu\text{A}$ (max)
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient (Note 7)	$I_R = 10$ mA	$\pm 10$	<b><math>\pm 25</math></b>	ppm/ $^\circ\text{C}$
		$I_R = 1$ mA	$\pm 10$		ppm/ $^\circ\text{C}$ (max)
		$I_R = 150 \mu\text{A}$	$\pm 10$		ppm/ $^\circ\text{C}$
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{RMIN} \leq I_R \leq 1$ mA	0.8	1.6	mV mV (max)
		$1$ mA $\leq I_R \leq 15$ mA	8.0	12.0 <b>23.0</b>	mV mV (max) mV (max)
$Z_R$	Reverse Dynamic Impedance	$I_R = 1$ mA, $f = 120$ Hz, $I_{AC} = 0.1 I_R$	0.7	1.7	$\Omega$ $\Omega$ (max)
$e_N$	Wideband Noise	$I_R = 150 \mu\text{A}$ $10$ Hz $\leq f \leq 10$ kHz	180		$\mu\text{V}_{rms}$
$\Delta V_R$	Reverse Breakdown Voltage Long Term Stability	$t = 1000$ hrs $T = 25^\circ\text{C} \pm 0.1^\circ\text{C}$ $I_R = 150 \mu\text{A}$	120		ppm

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions, see the 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:** The maximum power dissipation must be derated at elevated temperatures and is dictated by  $T_{Jmax}$  (maximum junction temperature),  $\theta_{JA}$  (junction to ambient thermal resistance), and  $T_A$  (ambient temperature). The maximum allowable power dissipation at any temperature is  $PD_{MAX} = (T_{Jmax} - T_A)/\theta_{JA}$  or the number given in the Absolute Maximum Ratings, whichever is lower. For the LM9140,  $T_{Jmax} = 125^\circ\text{C}$ , and the typical thermal resistance ( $\theta_{JA}$ ), when board mounted, is  $170^\circ\text{C/W}$  with  $0.125''$  lead length for the TO-92 package.

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

**Note 4:** Typical values are at  $T_J = 25^\circ\text{C}$  and represent most likely parametric norm.

**Note 5:** Limits are 100% production tested at  $25^\circ\text{C}$ . Limits over temperature are guaranteed through correlation using Statistical Quality Control (SQC) methods. The limits are used to calculate National's AOQL.

**Note 6:** The boldface (over-temperature) limit for Reverse Breakdown Voltage Tolerance is defined as a room temperature Reverse Breakdown Voltage Tolerance  $\pm [\Delta V_R/\Delta T] (65^\circ\text{C}) (V_R)$ .  $\Delta V_R/\Delta T$  is the  $V_R$  temperature coefficient,  $65^\circ\text{C}$  is the temperature range from  $-40^\circ\text{C}$  to the reference point of  $25^\circ\text{C}$ , and  $V_R$  is the reverse breakdown voltage. The total over-temperature tolerance for the different grades is shown below:

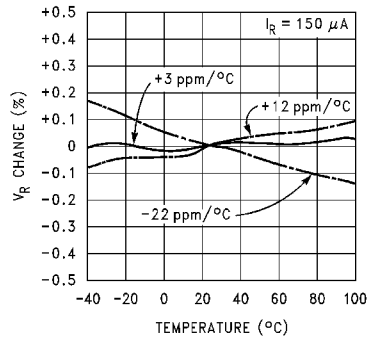
B-grade:  $\pm 0.66\% = \pm 0.5\% \pm 25$  ppm/ $^\circ\text{C} \times 65^\circ\text{C}$

Therefore, as an example, the B-grade LM9140-2.5 has an over-temperature Reverse Breakdown Voltage tolerance of  $\pm 2.5\text{V} \times 0.66\% = \pm 16.6$  mV.

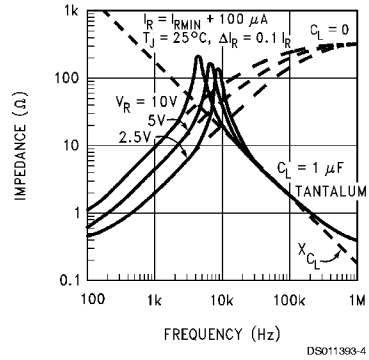
**Note 7:** The average temperature coefficient is defined as the maximum deviation of reference voltage at all measured temperatures between the operating  $T_{MAX}$  and  $T_{MIN}$ , divided by  $T_{MAX} - T_{MIN}$ . The measured temperatures are  $-55^\circ\text{C}$ ,  $-40^\circ\text{C}$ ,  $0^\circ\text{C}$ ,  $25^\circ\text{C}$ ,  $70^\circ\text{C}$ ,  $85^\circ\text{C}$  and  $125^\circ\text{C}$ .

# Typical Performance Characteristics

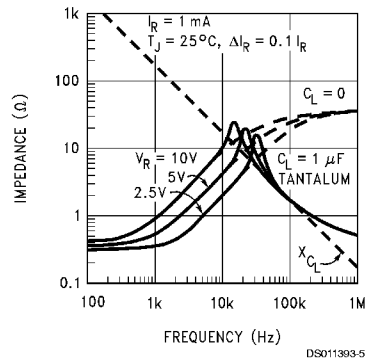
**Temperature Drift for Different Average Temperature Coefficient**



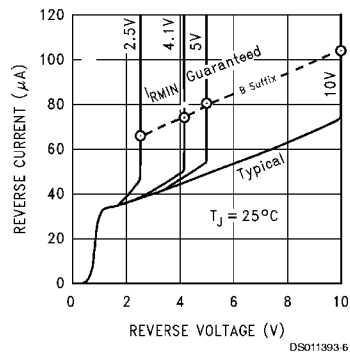
**Output Impedance vs Frequency**



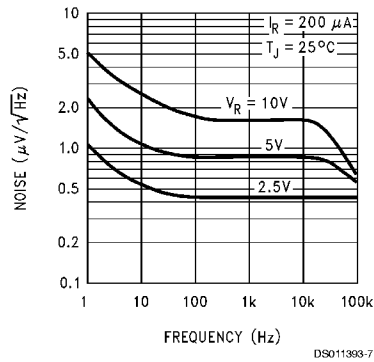
**Output Impedance vs Frequency**



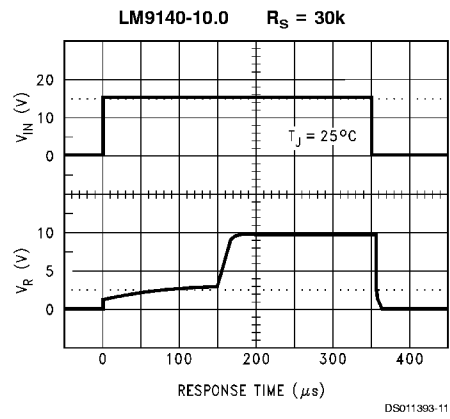
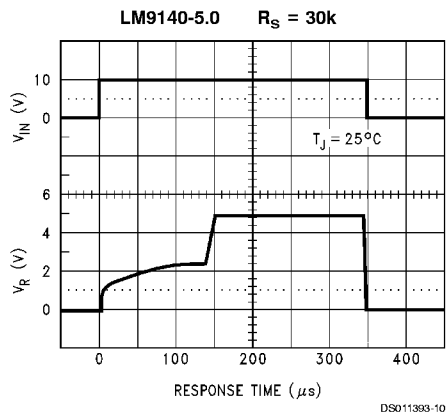
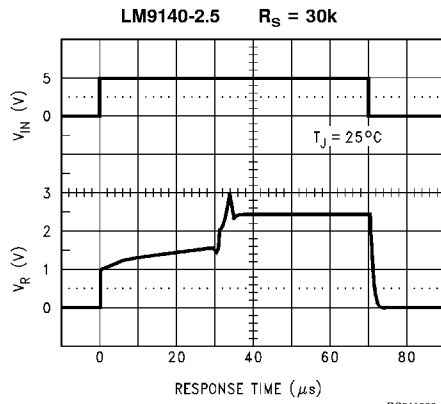
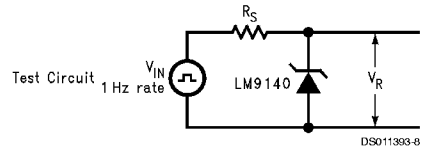
**Reverse Characteristics and Minimum Operating Current**



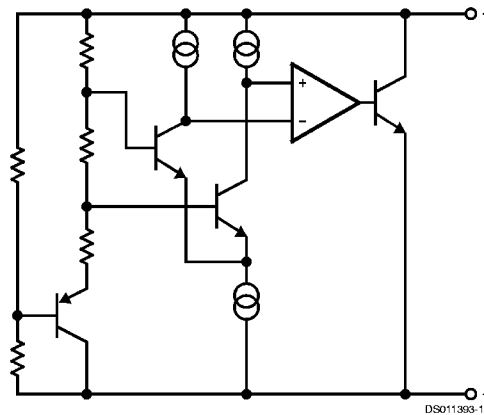
**Noise Voltage vs Frequency**



## Start-Up Characteristics



## Functional Block Diagram



## Applications Information

The LM9140 is a precision micro-power curvature-corrected bandgap shunt voltage reference. The LM9140 has been designed for stable operation without the need of an external capacitor connected between the “+” pin and the “-” pin. If, however, a bypass capacitor is used, the LM9140 remains stable. Reducing design effort is the availability of several fixed reverse breakdown voltages: 2.500V, 4.096V, 5.000V, and 10.000V. The minimum operating current increases from 60  $\mu$ A for the LM9140-2.5 to 100  $\mu$ A for the LM9140-10.0. All versions have a maximum operating current of 15 mA.

The 4.096V version allows single +5V 12-bit ADCs or DACs to operate with an LSB equal to 1 mV. For 12-bit ADCs or DACs that operate on supplies of 10V or greater, the 8.192V version gives 2 mV per LSB.

In a conventional shunt regulator application (Figure 1), an external series resistor ( $R_S$ ) is connected between the sup-

ply voltage and the LM9140.  $R_S$  determines the current that flows through the load ( $I_L$ ) and the LM9140 ( $I_Q$ ). Since load current and supply voltage may vary,  $R_S$  should be small enough to supply at least the minimum acceptable  $I_Q$  to the LM9140 even when the supply voltage is at its minimum and the load current is at its maximum value. When the supply voltage is at its maximum and  $I_L$  is at its minimum,  $R_S$  should be large enough so that the current flowing through the LM9140 is less than 15 mA.

$R_S$  is determined by the supply voltage, ( $V_S$ ), the load and operating current, ( $I_L$  and  $I_Q$ ), and the LM9140’s reverse breakdown voltage,  $V_R$ .

$$R_S = \frac{V_S - V_R}{I_L + I_Q}$$

## Typical Applications

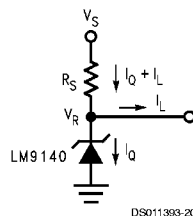
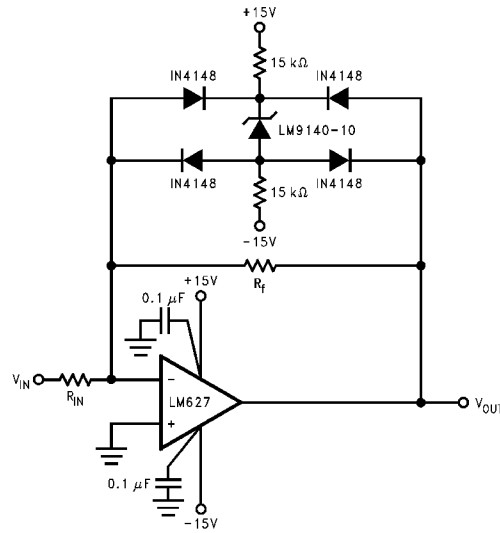


FIGURE 1. Shunt Regulator



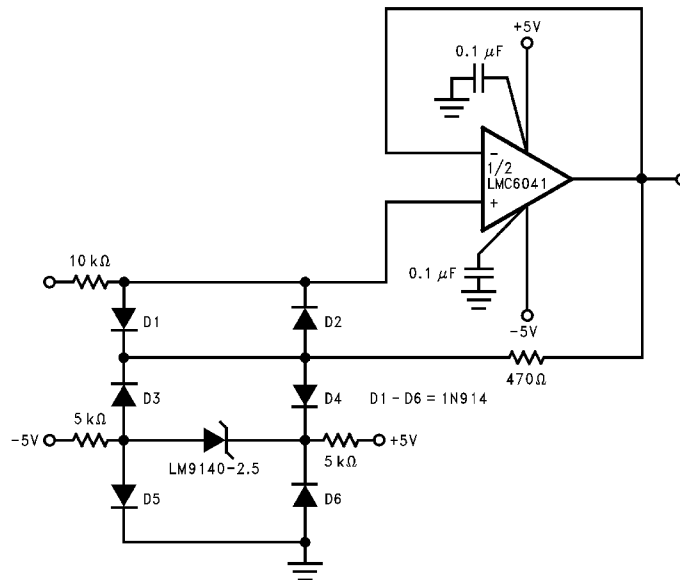


## Typical Applications (Continued)



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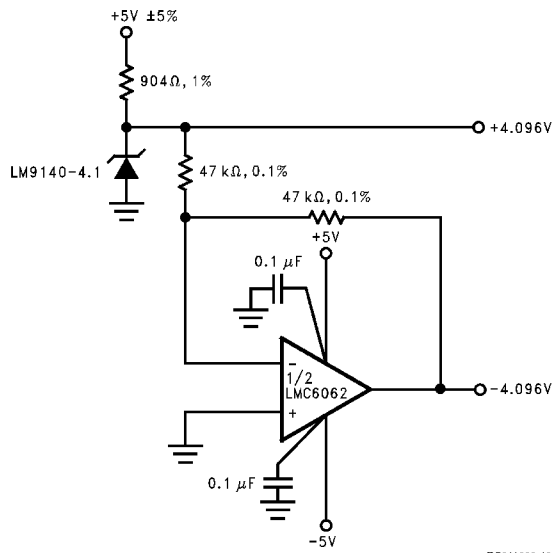
**FIGURE 3. Bounded amplifier reduces saturation-induced delays and can prevent succeeding stage damage. Nominal clamping voltage is  $\pm 11.5V$  (LM9140's reverse breakdown voltage +2 diode  $V_f$ ).**



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**FIGURE 4. Protecting Op Amp input. The bounding voltage is  $\pm 4V$  with the LM9140-2.5 (LM9140's reverse breakdown voltage + 3 diode  $V_f$ ).**

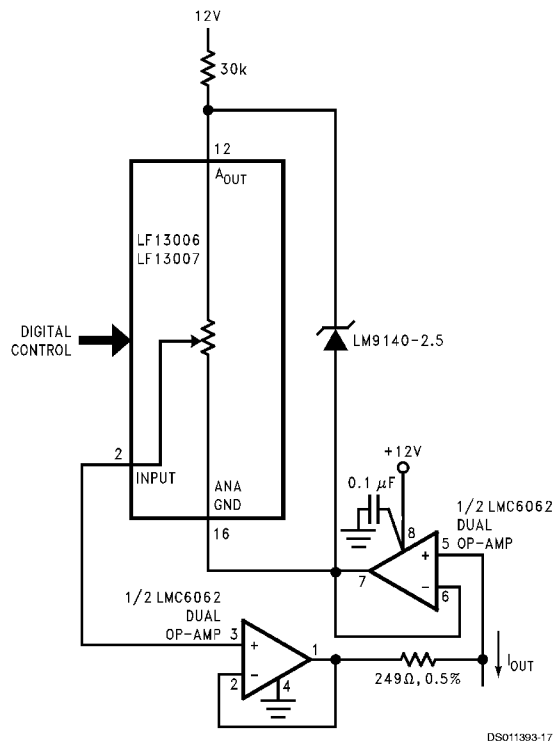
## Typical Applications (Continued)



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FIGURE 5. Precision ±4.096V Reference

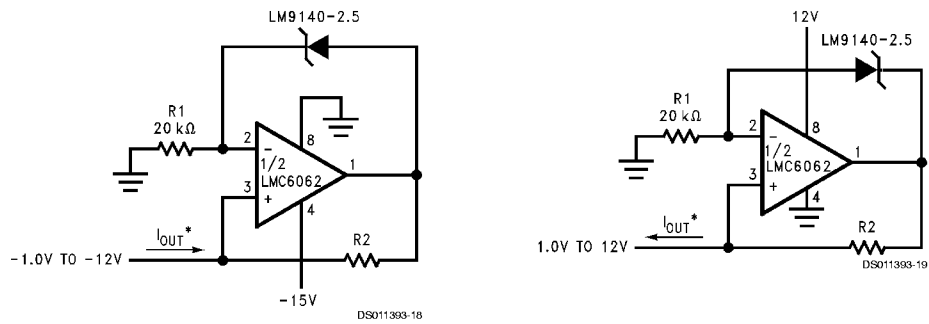
## Typical Applications (Continued)



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$$I_{OUT} = \frac{2.5V}{249\Omega} \left[ \frac{1}{\text{gain set \#}} \right]$$

FIGURE 6. Programmable Current Source

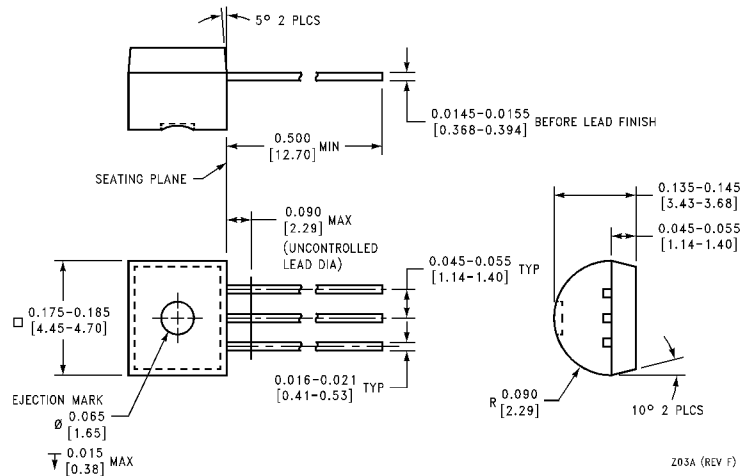


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$$I_{OUT}^* = \frac{2.5V}{R2}$$

FIGURE 7. Precision 1 μA to 1 mA Current Sources

**Physical Dimensions** inches (millimeters) unless otherwise noted



**TO-92 Package**  
**NS Package Number Z03A**

Z03A (REV F)

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