



SBOS193B – MARCH 2001 – REVISED JUNE 2004

# High-Side, Bidirectional CURRENT SHUNT MONITOR

## FEATURES

- COMPLETE BIDIRECTIONAL CURRENT MEASUREMENT CIRCUIT
- WIDE SUPPLY RANGE: 2.7V to 40V
- SUPPLY-INDEPENDENT COMMON-MODE VOLTAGE: 2.7V TO 60V
- RESISTOR PROGRAMMABLE GAIN SET
- LOW QUIESCENT CURRENT: 75 $\mu$ A (typ)
- MSOP-8 PACKAGE

## APPLICATIONS

- CURRENT SHUNT MEASUREMENT:  
Automotive, Telephone, Computers, Power Systems, Test, General Instrumentation
- PORTABLE AND BATTERY-BACKUP SYSTEMS
- BATTERY CHARGERS
- POWER MANAGEMENT
- CELL PHONES

## DESCRIPTION

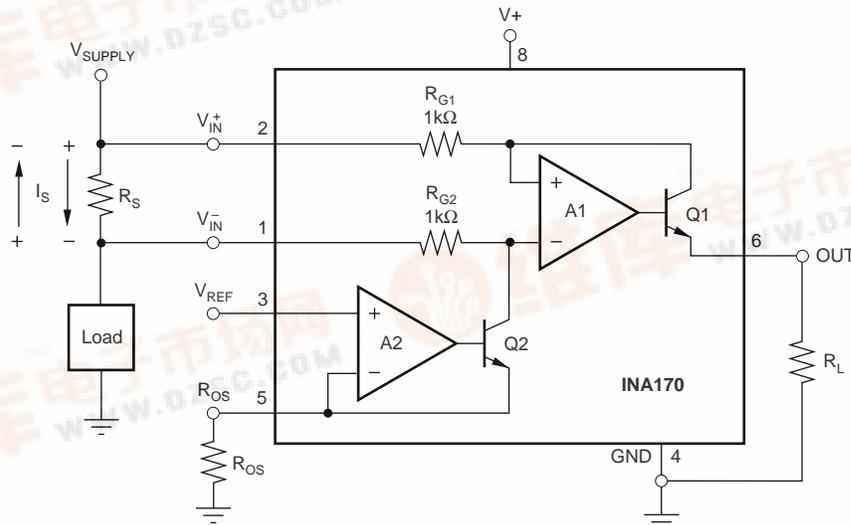
The INA170 is a high-side, bidirectional current shunt monitor featuring a wide input common-mode voltage range, low quiescent current, and a tiny MSOP-8 package.

Bidirectional current measurement is accomplished by output offsetting. The offset voltage level is set with an external resistor and voltage reference. This permits measurement of a bidirectional shunt current while using a single supply for the INA170.

Input common-mode and power-supply voltages are independent. Input voltage can range from +2.7V to +60V on any supply voltage from +2.7V to +40V. Low 10 $\mu$ A input bias current adds minimal error to the shunt current.

The INA170 converts a differential input voltage to a current output. This current develops a voltage across an external load resistor, setting any gain from 1 to over 100.

The INA170 is available in an MSOP-8 package, and is specified over the extended industrial temperature range, -40°C to +85°C with operation from -55°C to +125°C.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

## PACKAGE/ORDERING INFORMATION

PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER <sup>(1)</sup>	TRANSPORT MEDIA
INA170EA "	MSOP-8 "	DGK "	-40°C to +85°C "	INA170EA "	INA170EA/250 INA170EA/2K5	Tape and Reel Tape and Reel

NOTE: (1) Models with a slash (/) are available only in Tape and Reel in the quantities indicated (e.g., /2K5 indicates 2500 devices per reel). Ordering 2500 pieces of "INA170NA/2K5" will get a single 2500-piece Tape and Reel.

## ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>

Supply Voltage, V+ to GND .....	-0.3V to 40V
Analog Inputs, Common Mode .....	-0.3V to 75V
Differential ( $V_{in+}$ ) - ( $V_{in-}$ ) .....	-40V to 2V
Analog Output, Out .....	-0.3V to 40V
Operating Temperature .....	-55°C to +125°C
Storage Temperature .....	-65°C to +150°C
Junction Temperature .....	+150°C
Lead Temperature (soldering, 10s) .....	+300°C

NOTE: (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.



## ELECTROSTATIC DISCHARGE SENSITIVITY

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.

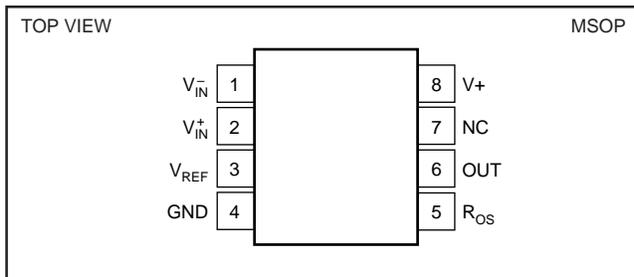
# ELECTRICAL CHARACTERISTICS

At  $T_A = -40^\circ\text{C}$  to  $+85^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{IN}^+ = 12\text{V}$ ,  $R_{OUT} = 25\text{k}\Omega$ , unless otherwise noted.

PARAMETER	CONDITION	INA170EA			UNITS
		MIN	TYP	MAX	
<b>INPUT</b>					
Full-Scale Sense (Input) Voltage	$V_{SENSE} = V_{IN}^+ - V_{IN}^-$		100	500	mV
Common-Mode Input Range		+2.7		+60	V
Common-Mode Rejection	$V_{IN}^+ = +2.7\text{V}$ to $+60\text{V}$ , $V_{SENSE} = 50\text{mV}$	100			dB
Offset Voltage <sup>(1)</sup> RTI			$\pm 0.2$	$\pm 1$	mV
vs Temperature	$T_{MIN}$ to $T_{MAX}$		1		$\mu\text{V}/^\circ\text{C}$
vs Power Supply	$V^+ = +2.7\text{V}$ to $+60\text{V}$ , $V_{SENSE} = 50\text{mV}$		0.1	10	$\mu\text{V}/\text{V}$
Input Bias Current	$V_{IN}^+$ , $V_{IN}^-$		10		$\mu\text{A}$
<b>OFFSETTING AMPLIFIER</b>					
Offsetting Equation	$V_{OS} = (R_L/R_{OS}) V_{REF}$			$V_S - 1$	V
Input Voltage		1			mV
Input Offset Voltage			$\pm 0.2$	$\pm 1$	mV
vs Temperature	$T_{MIN}$ to $T_{MAX}$		10		$\mu\text{V}/^\circ\text{C}$
Programming Current through $R_{OS}$		0		1	mA
Input Impedance			$10^{10} \parallel 4$		$\Omega \parallel \text{pF}$
Input Bias Current	$V_{IN}^+$ , $V_{IN}^-$		+10		nA
<b>OUTPUT</b>					
Transconductance	$V_{SENSE} = 10\text{mV}$ to $150\text{mV}$	0.990	1	1.01	mA/V
vs Temperature	$V_{SENSE} = 100\text{mV}$		50		nA/ $^\circ\text{C}$
Nonlinearity Error	$V_{SENSE} = 10\text{mV}$ to $150\text{mV}$		$\pm 0.01$	$\pm 0.1$	%
Total Output Error	$V_{SENSE} = 100\text{mV}$		$\pm 0.5$	$\pm 2$	%
Output Impedance			$1 \parallel 5$		$\text{G}\Omega \parallel \text{pF}$
Voltage Output					V
Swing to Power Supply, $V^+$			$(V^+) - 0.9$	$(V^+) - 1.2$	V
Swing to Common Mode, $V_{CM}$			$V_{CM} - 0.6$	$V_{CM} - 1.0$	V
<b>FREQUENCY RESPONSE</b>					
Bandwidth	$R_{OUT} = 10\text{k}\Omega$		400		kHz
Settling Time (0.1%)	5V Step, $R_{OUT} = 10\text{k}\Omega$		3		$\mu\text{s}$
<b>NOISE</b>					
Output-Current Noise Density			20		$\text{pA}/\sqrt{\text{Hz}}$
Total Output-Current Noise	BW = 100kHz		7		nA RMS
<b>POWER SUPPLY</b>					
Operating Range	$V^+$	+2.7		+40	V
Quiescent Current	$V_{SENSE} = 0$ , $I_O = 0$		75	125	$\mu\text{A}$
<b>TEMPERATURE RANGE</b>					
Specification, $T_{MIN}$ to $T_{MAX}$		-40		+85	$^\circ\text{C}$
Operating		-55		+125	$^\circ\text{C}$
Storage		-65		+150	$^\circ\text{C}$
Thermal Resistance, $\theta_{JA}$			150		$^\circ\text{C}/\text{W}$

NOTE: (1) Defined as the amount of input voltage,  $V_{SENSE}$ , to drive the output to zero.

## PIN CONFIGURATION

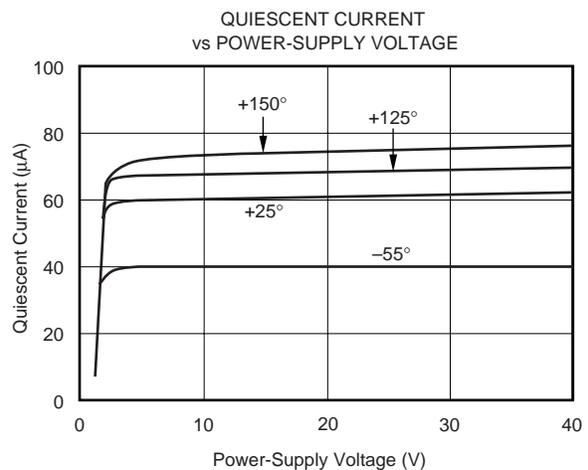
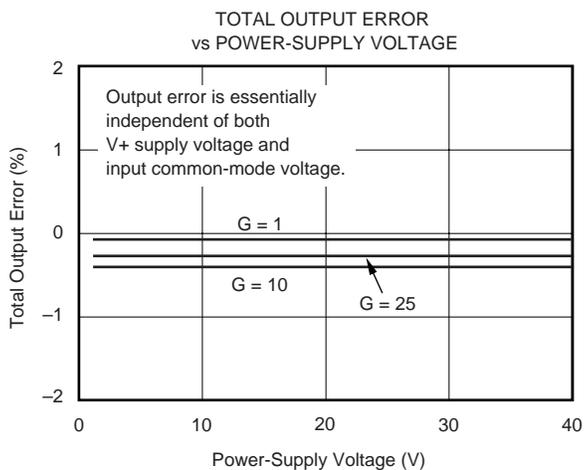
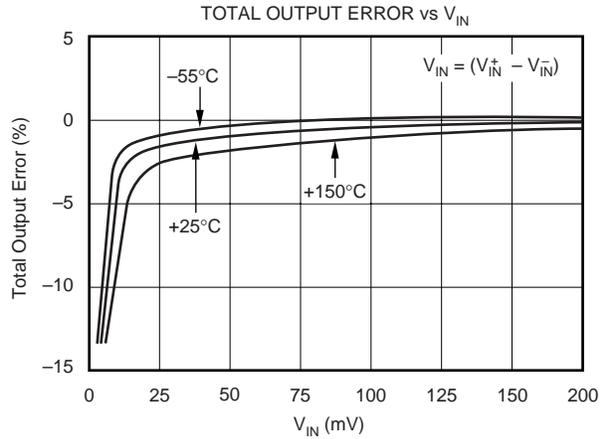
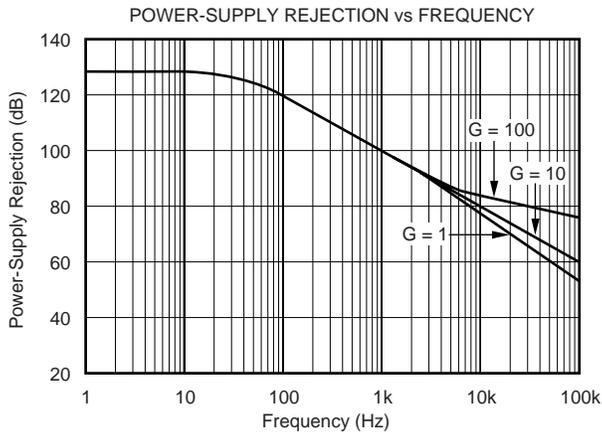
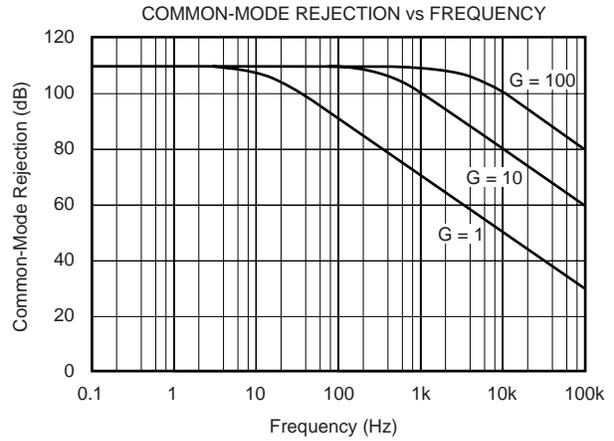
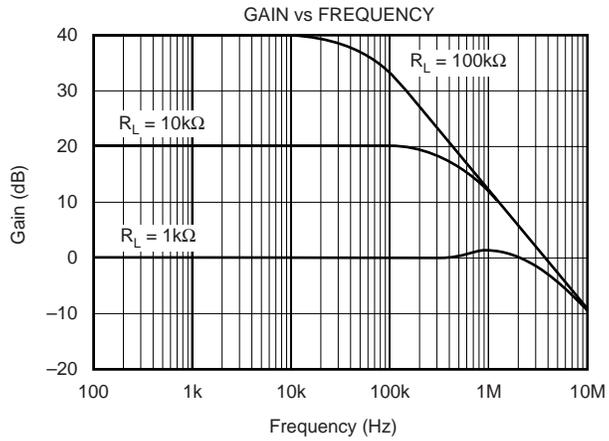


## PIN DESCRIPTION

PIN	DESIGNATOR	DESCRIPTION
1	$V_{IN}^-$	Inverting Input
2	$V_{IN}^+$	Noninverting Input
3	$V_{REF}$	Reference Voltage Input
4	GND	Ground
5	$R_{OS}$	Offset Resistor
6	OUT	Output
7	NC	No Connection
8	$V^+$	Supply Voltage

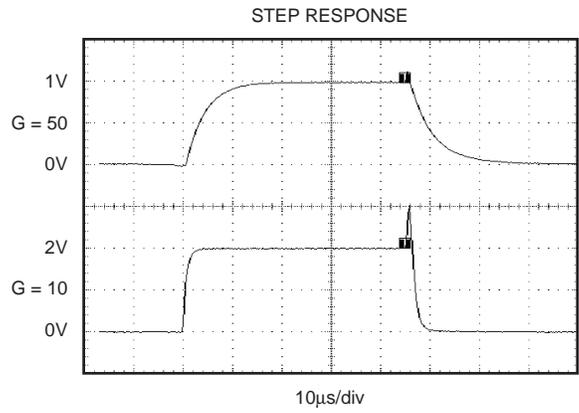
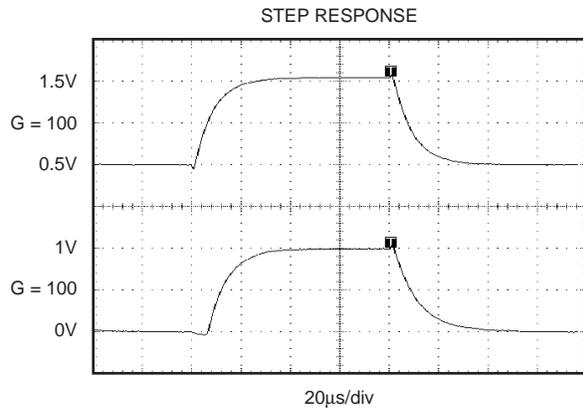
# TYPICAL CHARACTERISTICS

At  $T_A = +25^\circ\text{C}$ ,  $V_+ = 5\text{V}$ ,  $V_{IN}^+ = 12\text{V}$ ,  $R_L = 25\text{k}\Omega$ , unless otherwise noted.



# TYPICAL CHARACTERISTICS (Cont.)

At  $T_A = +25^\circ\text{C}$ ,  $V_+ = 5\text{V}$ ,  $V_{IN}^+ = 12\text{V}$ ,  $R_L = 25\text{k}\Omega$ , unless otherwise noted.



# OPERATION

Figure 1 shows the basic circuit diagram for the INA170. Load current  $I_S$  is drawn from supply  $V_S$  through shunt resistor  $R_S$ . The voltage drop in shunt resistor  $V_S$  is forced across  $R_{G1}$  by the internal op-amp, causing current to flow into the collector of Q1. External resistor  $R_L$  converts the output current to a voltage,  $V_{OUT}$ , at the OUT pin.

Without offset, the transfer function for the INA170 is:

$$I_O = g_m (V_{IN}^+ - V_{IN}^-) \quad (1)$$

$$\text{where } g_m = 1000\mu\text{A/V} \quad (2)$$

In the circuit of Figure 1, the input voltage,  $(V_{IN}^+ - V_{IN}^-)$ , is equal to  $I_S \cdot R_S$  and the output voltage,  $V_{OUT}$ , is equal to  $I_O \cdot R_L$ . The transconductance,  $g_m$ , of the INA170 is  $1000\mu\text{A/V}$ . The complete transfer function for the current measurement amplifier in this application is:

$$V_{OUT} = (I_S) (R_S) (1000\mu\text{A/V}) (R_L) \quad (3)$$

Applying a positive reference voltage to pin 3 causes a current to flow through  $R_{OS}$ , forcing output current  $I_O$  to be offset from zero. The transfer function then becomes:

$$V_{OUT} = \left( \frac{V_{REF} \cdot R_L}{R_{OS}} \right) \pm \left( \frac{I_S \cdot R_S \cdot R_L}{1k\Omega} \right) \quad (4)$$

The maximum differential input voltage for accurate measurements is 0.5V, which produces a  $500\mu\text{A}$  output current. A differential input voltage of up to 2V will not cause damage. Differential measurements (pins 1 and 2) can be

bipolar with a more-positive voltage applied to pin 2. If a more-negative voltage is applied to pin 1, output current  $I_O$  will decrease towards zero.

## BASIC CONNECTION

Figure 1 shows the basic connection of the INA170. The input pins,  $V_{IN}^+$  and  $V_{IN}^-$ , should be connected as closely as possible to the shunt resistor to minimize any resistance in series with the shunt resistance. The output resistor,  $R_L$ , is shown connected between pin 6 and ground. Best accuracy is achieved with the output voltage measured directly across  $R_L$ . This is especially important in high-current systems where load current could flow in the ground connections, affecting the measurement accuracy.

No power-supply bypass capacitors are required for stability of the INA170. However, applications with noisy or high impedance power supplies may require de-coupling capacitors to reject power-supply noise. Connect bypass capacitors close to the device pins.

## POWER SUPPLIES

The input circuitry of the INA170 can accurately measure beyond its power-supply voltage,  $V+$ . For example, the  $V+$  power supply can be 5V, while the load power-supply voltage (INA170 input voltage) is up to +60V. However, the output-voltage range of the OUT terminal (pin 6) is limited by the supply.

## SELECTING $R_S$ AND $R_L$

The value chosen for the shunt resistor,  $R_S$ , depends on the application and is a compromise between small-signal accuracy and maximum permissible voltage loss in the measurement line. High values of  $R_S$  provide better accuracy at lower

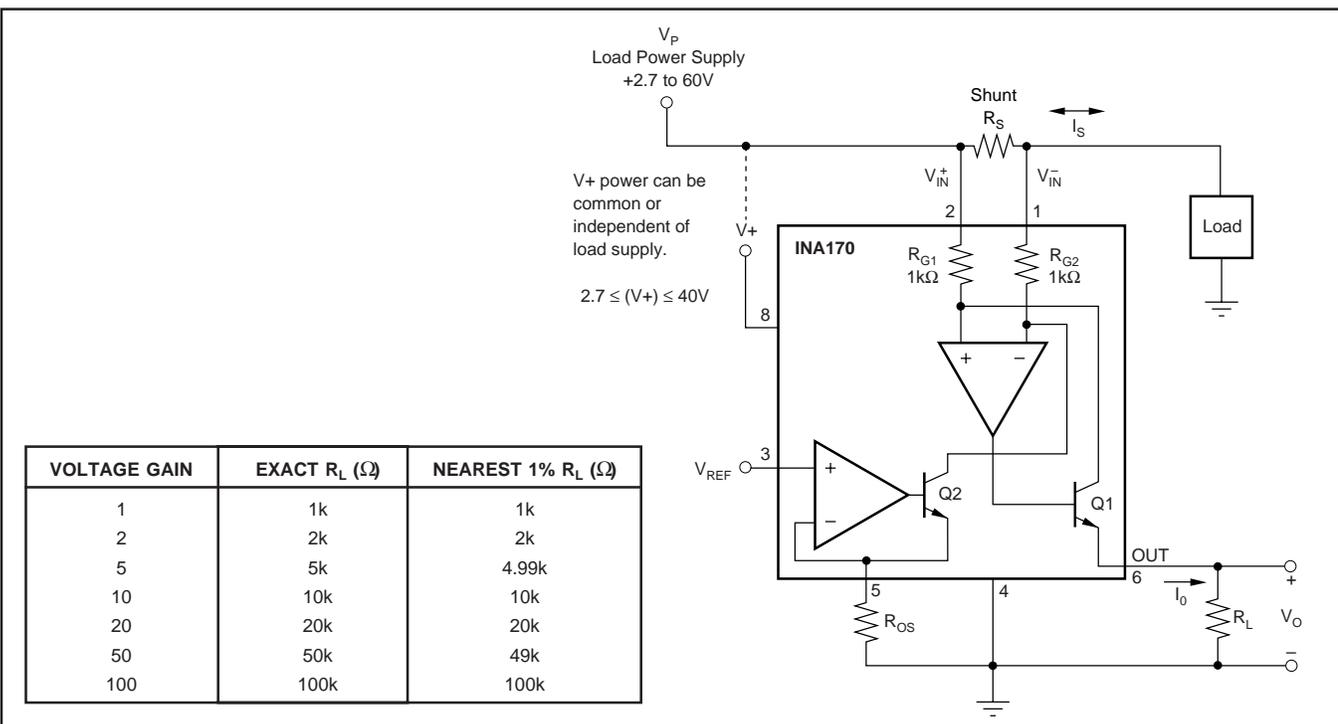


FIGURE 1. Basic Circuit Connections.

currents by minimizing the effects of offset, while low values of  $R_S$  minimize voltage loss in the supply line. For most applications, best performance is attained with an  $R_S$  value that provides a full-scale shunt voltage of 50mV to 100mV. Maximum input voltage for accurate measurements is 500mV.

$R_L$  is chosen to provide the desired full-scale output voltage. The output impedance of the INA170 Out terminal is very high which permits using values of  $R_L$  up to 100k $\Omega$  with excellent accuracy. The input impedance of any additional circuitry at the output should be much higher than the value of  $R_L$  to avoid degrading accuracy.

Some Analog-to-Digital (A/D) converters have input impedances that will significantly affect measurement gain. The input impedance of the A/D converter can be included as part of the effective  $R_L$  if its input can be modeled as a resistor to ground. Alternatively, an op-amp can be used to buffer the A/D converter input, as shown in Figure 2. See Figure 1 for recommended values of  $R_L$ .

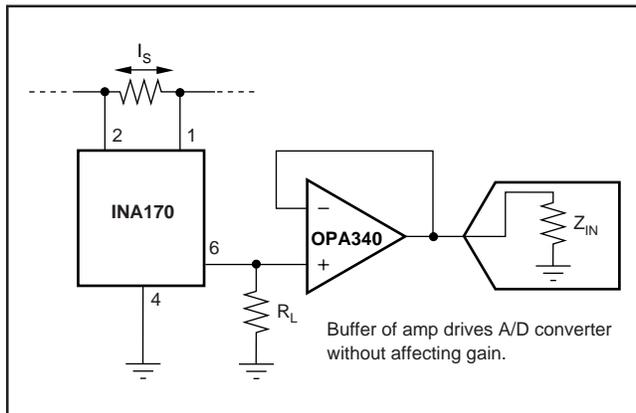


FIGURE 2. Buffering Output to Drive A/D Converter.

### OUTPUT VOLTAGE RANGE

The output of the INA170 is a current, which is converted to a voltage by the load resistor,  $R_L$ . The output current remains accurate within the *compliance voltage range* of the output circuitry. The shunt voltage and the input common-mode and power supply voltages limit the maximum possible

output swing. The maximum output voltage compliance is limited by the lower of the two equations below:

$$V_{out\ max} = (V+) - 0.7V - (V_{IN}^+ - V_{IN}^-) \quad (5)$$

or

$$V_{out\ max} = V_{IN}^- - 0.5V \quad (6)$$

(whichever is lower)

### BANDWIDTH

Measurement bandwidth is affected by the value of the load resistor,  $R_L$ . High gain produced by high values of  $R_L$  will yield a narrower measurement bandwidth (see Typical Performance Curves). For widest possible bandwidth, keep the capacitive load on the output to a minimum.

If bandwidth limiting (filtering) is desired, a capacitor can be added to the output, as shown in Figure 3. This will not cause instability.

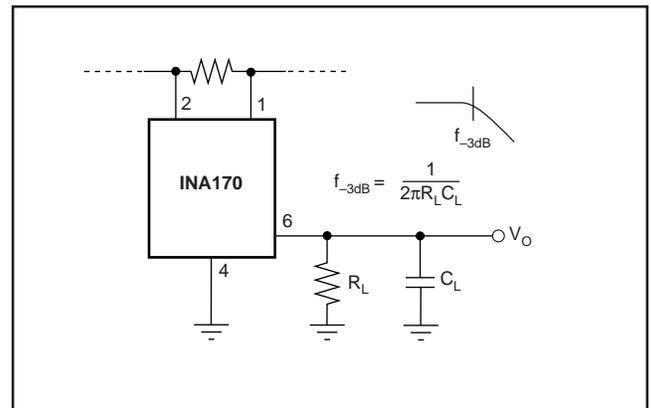


FIGURE 3. Output Filter.

### APPLICATIONS

The INA170 is designed for current shunt measurement circuits as shown in Figure 1, but its basic function is useful in a wide range of circuitry. A creative engineer will find many unforeseen uses in measurement and level shifting circuits.

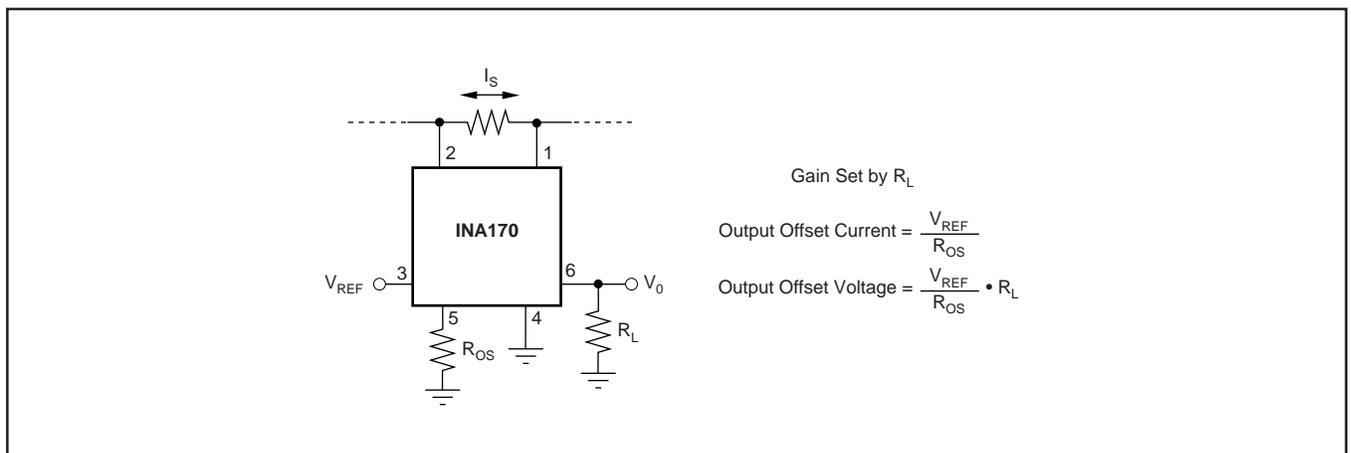


FIGURE 4. Offsetting the Output Voltage.

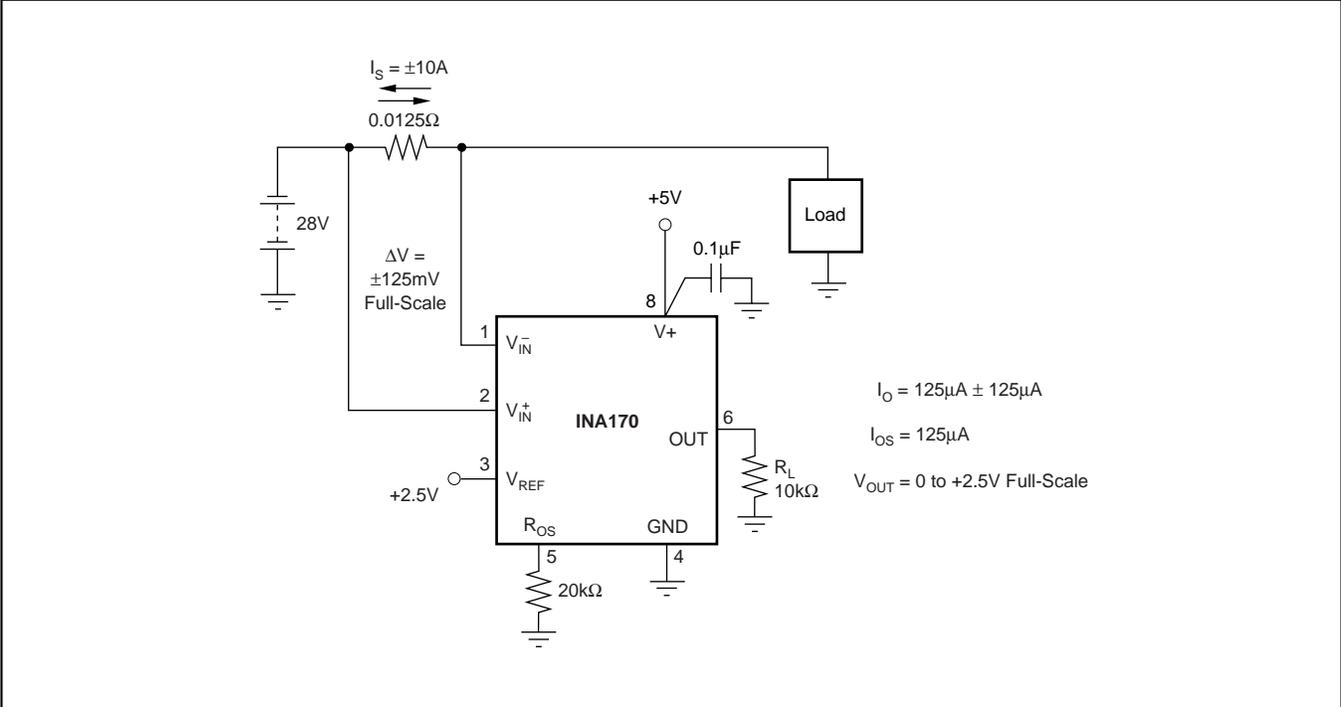
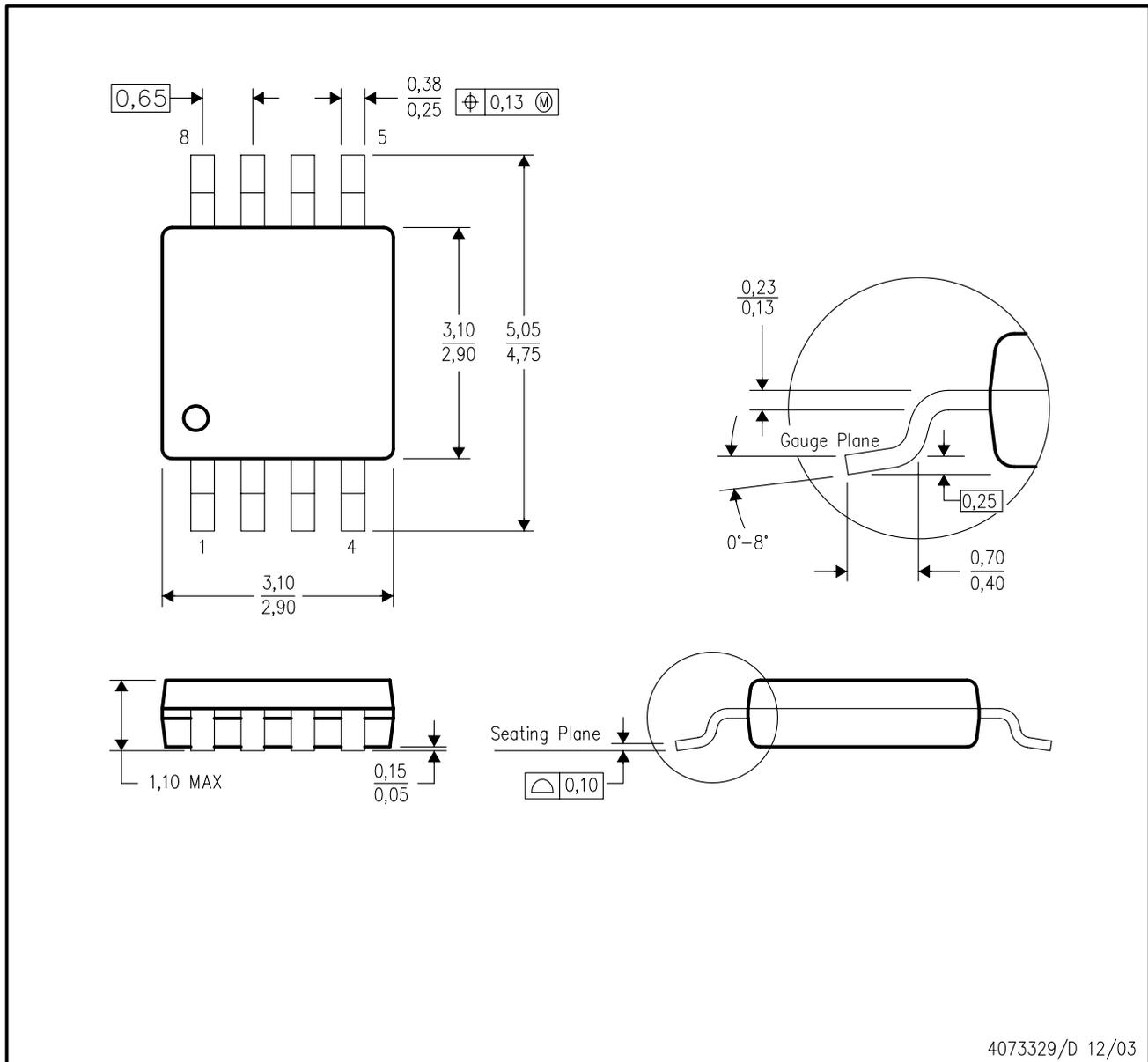


FIGURE 5. Bipolar Current Measurement.

# MECHANICAL DATA

DGK (S-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Body dimensions do not include mold flash or protrusion.
  - D. Falls within JEDEC MO-187 variation AA.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

<b>Products</b>		<b>Applications</b>	
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>	Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>	Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>	Broadband	<a href="http://www.ti.com/broadband">www.ti.com/broadband</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>	Digital Control	<a href="http://www.ti.com/digitalcontrol">www.ti.com/digitalcontrol</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>	Military	<a href="http://www.ti.com/military">www.ti.com/military</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>	Optical Networking	<a href="http://www.ti.com/opticalnetwork">www.ti.com/opticalnetwork</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>	Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
		Telephony	<a href="http://www.ti.com/telephony">www.ti.com/telephony</a>
		Video & Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>
		Wireless	<a href="http://www.ti.com/wireless">www.ti.com/wireless</a>

Mailing Address: Texas Instruments  
Post Office Box 655303 Dallas, Texas 75265