



# High-Side Measurement CURRENT SHUNT MONITOR

## FEATURES

- COMPLETE UNIPOLAR HIGH-SIDE CURRENT MEASUREMENT CIRCUIT
- WIDE SUPPLY AND COMMON-MODE RANGE
- INA138: 2.7V to 36V
- INA168: 2.7V to 60V
- INDEPENDENT SUPPLY AND INPUT COMMON-MODE VOLTAGES
- SINGLE RESISTOR GAIN SET
- LOW QUIESCENT CURRENT (25 $\mu$ A typ)
- WIDE TEMPERATURE RANGE:  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$
- SOT23-5 PACKAGE

## APPLICATIONS

- CURRENT SHUNT MEASUREMENT: Automotive, Telephone, Computers
- PORTABLE AND BATTERY-BACKUP SYSTEMS
- BATTERY CHARGERS
- POWER MANAGEMENT
- CELL PHONES
- PRECISION CURRENT SOURCE

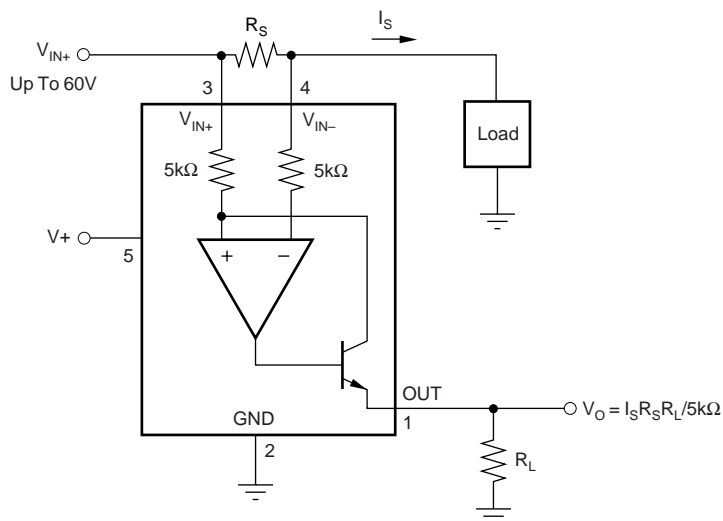
## DESCRIPTION

The INA138 and INA168 are high-side, unipolar, current shunt monitors. Wide input common-mode voltage range, low quiescent current, and tiny SOT23 packaging enable use in a variety of applications.

Input common-mode and power-supply voltages are independent and can range from 2.7V to 36V for the INA138 and 2.7V to 60V for the INA168. Quiescent current is only 25 $\mu$ A, which permits connecting the power supply to either side of the current measurement shunt with minimal error.

The device converts a differential input voltage to a current output. This current is converted back to a voltage with an external load resistor that sets any gain from 1 to over 100. Although designed for current shunt measurement, the circuit invites creative applications in measurement and level shifting.

Both the INA138 and INA168 are available in SOT23-5 and are specified for the  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  temperature range.



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<sup>(1)</sup>

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
INA138	SOT23-5 Surface-Mount	DBV	-40°C to +125°C	B38	INA138NA/250	Tape and Reel, 250
"	"	"	"	"	INA138NA/3K	Tape and Reel, 3000
INA168	SOT23-5 Surface-Mount	DBV	-40°C to +125°C	A68	INA168NA/250	Tape and Reel, 250
"	"	"	"	"	INA168NA/3K	Tape and Reel, 3000

NOTE: (1) For the most current package and ordering information, see the Package Option Addendum located at the end of the data sheet.

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

Supply Voltage, V+	
INA138	-0.3V to 60V
INA168	-0.3V to 75V
Analog Inputs, V <sub>IN+</sub> , V <sub>IN-</sub>	
INA138	
Common Mode	-0.3V to 60V
Differential (V <sub>IN+</sub> ) - (V <sub>IN-</sub> )	-40V to 2V
INA168	
Common Mode	-0.3V to 75V
Differential (V <sub>IN+</sub> ) - (V <sub>IN-</sub> )	-40V to 2V
Analog Output, Out	-0.3V to 40V
Operating Temperature	-55°C to +150°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.

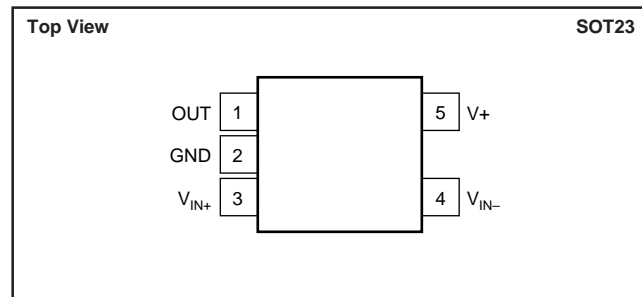


## ELECTROSTATIC DISCHARGE SENSITIVITY

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.

## PIN CONFIGURATION



# ELECTRICAL CHARACTERISTICS

**Boldface** limits apply over the specified temperature range,  $T_A = -40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ .

All other characteristics at  $T_A = +25^{\circ}\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{IN+} = 12\text{V}$ , and  $R_{OUT} = 125\text{k}\Omega$ , unless otherwise noted.

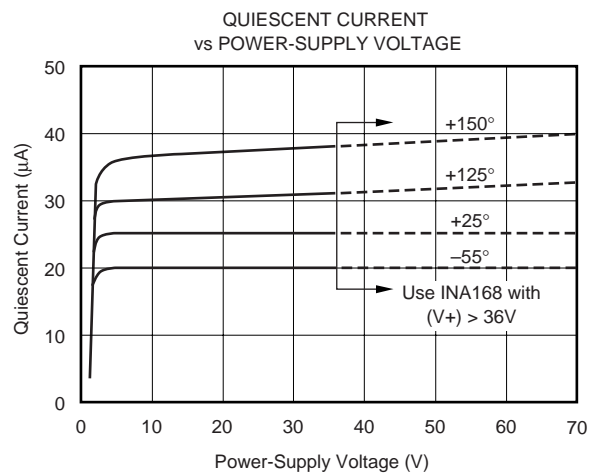
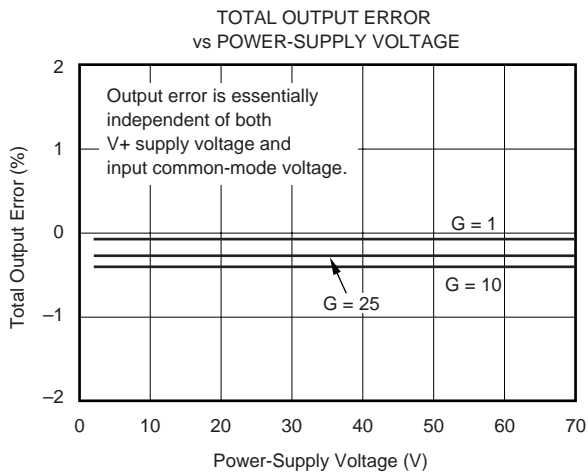
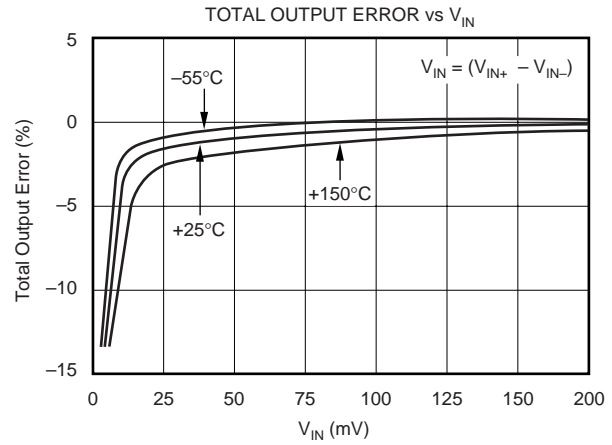
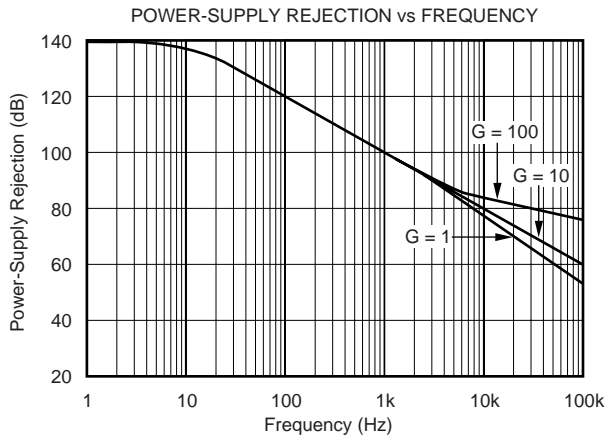
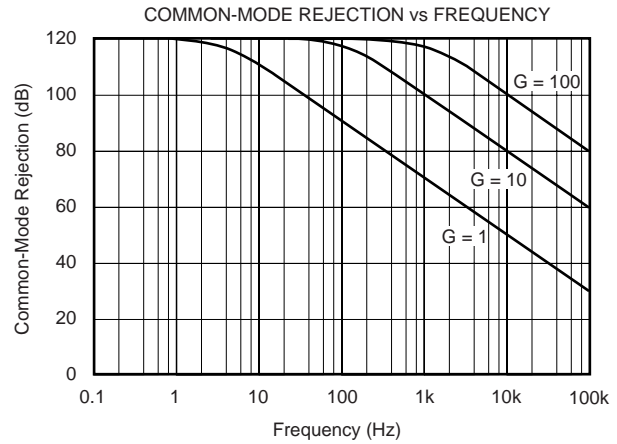
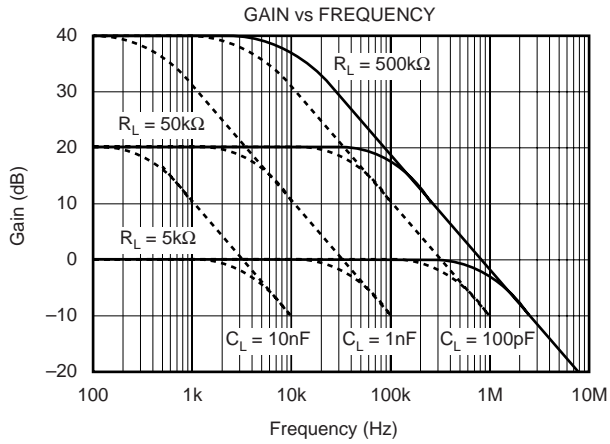
PARAMETER	CONDITION	INA138NA			INA168NA			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
<b>INPUT</b>								
Full-Scale Sense Voltage	$V_{SENSE} = V_{IN+} - V_{IN-}$		100	500		*	*	mV
Common-Mode Input Range		2.7		36	*		60	V
Common-Mode Rejection	$V_{IN+} = 2.7\text{V}$ to $40\text{V}$ , $V_{SENSE} = 50\text{mV}$ $V_{IN+} = 2.7\text{V}$ to $60\text{V}$ , $V_{SENSE} = 50\text{mV}$	100	120		100	120		dB
Offset Voltage <sup>(1)</sup>			$\pm 0.2$	$\pm 1$		*	*	mV
<b>Over Temperature vs Temperature</b>			<b>1</b>	<b><math>\pm 2</math></b>		*	*	mV
vs Power Supply, $V+$	$V- = 2.7\text{V}$ to $40\text{V}$ , $V_{SENSE} = 50\text{mV}$ $V- = 2.7\text{V}$ to $60\text{V}$ , $V_{SENSE} = 50\text{mV}$		0.1	10			10	$\mu\text{V}/^{\circ}\text{C}$ $\mu\text{V}/\text{V}$ $\mu\text{V}/\text{V}$
Input Bias Current vs Temperature			2	<b>10</b>		*		$\mu\text{A}$ $\mu\text{A}$
<b>OUTPUT</b>								
Transconductance	$T_A = +25^{\circ}\text{C}$ , $V_{SENSE} = 10\text{mV} - 150\text{mV}$	198	200	202	*	*	*	$\mu\text{A}/\text{V}$
<b>Over Temperature vs Temperature</b>	$V_{SENSE} = 100\text{mV}$	<b>196</b>	<b>10</b>	<b>204</b>	*	*	*	$\mu\text{A}/\text{V}$ $\text{nA}/^{\circ}\text{C}$
Nonlinearity Error	$V_{SENSE} = 10\text{mV}$ to $150\text{mV}$		$\pm 0.01$	$\pm 0.1$		*	*	%
Total Output Error	$V_{SENSE} = 100\text{mV}$		$\pm 0.5$	$\pm 2$		*	*	%
<b>Over Temperature</b>			<b><math>\pm 2.5</math></b>			*	*	%
Output Impedance			1    5			*		$\text{G}\Omega$    pF
Voltage Output Swing to Power Supply, $V+$			$(V+) - 0.8$	$(V+) - 1.0$		*	*	V
Swing to Common Mode, $V_{CM}$			$V_{CM} - 0.5$	$V_{CM} - 0.8$		*	*	V
<b>FREQUENCY RESPONSE</b>								
Bandwidth	$R_{OUT} = 5\text{k}\Omega$		800			*		kHz
	$R_{OUT} = 125\text{k}\Omega$		32			*		kHz
Settling Time (0.1%)	5V Step, $R_{OUT} = 5\text{k}\Omega$		1.8			*		$\mu\text{s}$
	5V Step, $R_{OUT} = 125\text{k}\Omega$		30			*		$\mu\text{s}$
<b>NOISE</b>								
Output-Current Noise Density			9			*		$\text{pA}/\sqrt{\text{Hz}}$
Total Output-Current Noise	BW = 100kHz		3			*		nA RMS
<b>POWER SUPPLY</b>								
Operating Range, $V+$		2.7		36	*		60	V
Quiescent Current	$T_A = +25^{\circ}\text{C}$ , $V_{SENSE} = 0$ , $I_O = 0$		25	45		*	*	$\mu\text{A}$
<b>Over Temperature</b>				<b>60</b>		*	*	$\mu\text{A}$
<b>TEMPERATURE RANGE</b>								
Specification, $T_{MIN}$ to $T_{MAX}$		-40		125	*		*	$^{\circ}\text{C}$
Operating		-55		150	*		*	$^{\circ}\text{C}$
Storage		-65		150	*		*	$^{\circ}\text{C}$
Thermal Resistance $\theta_{JA}$			200			*	*	$^{\circ}\text{C}/\text{W}$

\* specification same as INA138NA

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

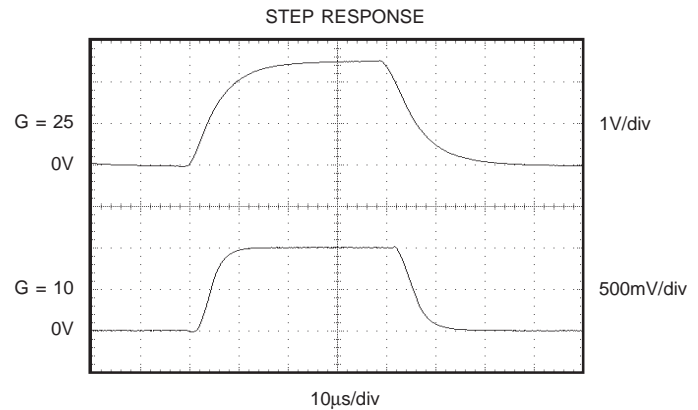
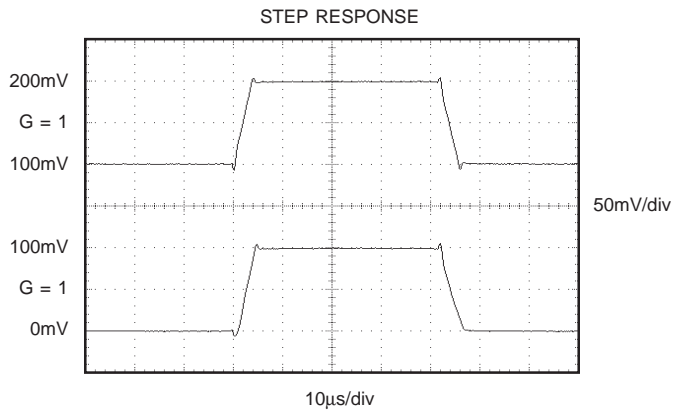
# TYPICAL CHARACTERISTICS

At  $T_A = +25^\circ\text{C}$ ,  $V_+ = 5\text{V}$ ,  $V_{IN+} = 12\text{V}$ , and  $R_L = 125\text{k}\Omega$ , unless otherwise noted.



# TYPICAL CHARACTERISTICS (Cont.)

At  $T_A = +25^\circ\text{C}$ ,  $V_+ = 5\text{V}$ ,  $V_{IN+} = 12\text{V}$ , and  $R_L = 125\text{k}\Omega$ , unless otherwise noted.



## OPERATION

Figure 1 illustrates the basic circuit diagram for both the INA138 and INA168. 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. The transfer function for the INA138 is:

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

where  $g_m = 200\mu\text{A/V}$ .

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 INA138 is  $200\mu\text{A/V}$ . The complete transfer function for the current measurement amplifier in this application is:

$$V_{OUT} = (I_S) (R_S) (200\mu\text{A/V}) (R_L) \quad (2)$$

The maximum differential input voltage for accurate measurements is 0.5V, which produces a  $100\mu\text{A}$  output current. A differential input voltage of up to 2V will not cause damage. Differential measurements (pins 3 and 4) must be unipolar with a more-positive voltage applied to pin 3. If a more-negative voltage is applied to pin 3, the output current,  $I_O$ , will be zero, but it will not cause damage.

## BASIC CONNECTION

Figure 1 shows the basic connection of the INA138. 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 1 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 INA138. However, applications with noisy or high-impedance power supplies may require decoupling capacitors to reject power-supply noise. Connect bypass capacitors close to the device pins.

## POWER SUPPLIES

The input circuitry of the INA138 can accurately measure beyond its power-supply voltage,  $V_+$ . For example, the  $V_+$  power supply can be 5V, whereas the load power supply voltage is up to +36V (or +60V with the INA168). The output voltage range of the OUT terminal, however, is limited by the lesser of the two voltages (see "Output Voltage Range" section).

## 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 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 range 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 INA138 OUT terminal is very high which permits using values of  $R_L$  up to 500k $\Omega$  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.

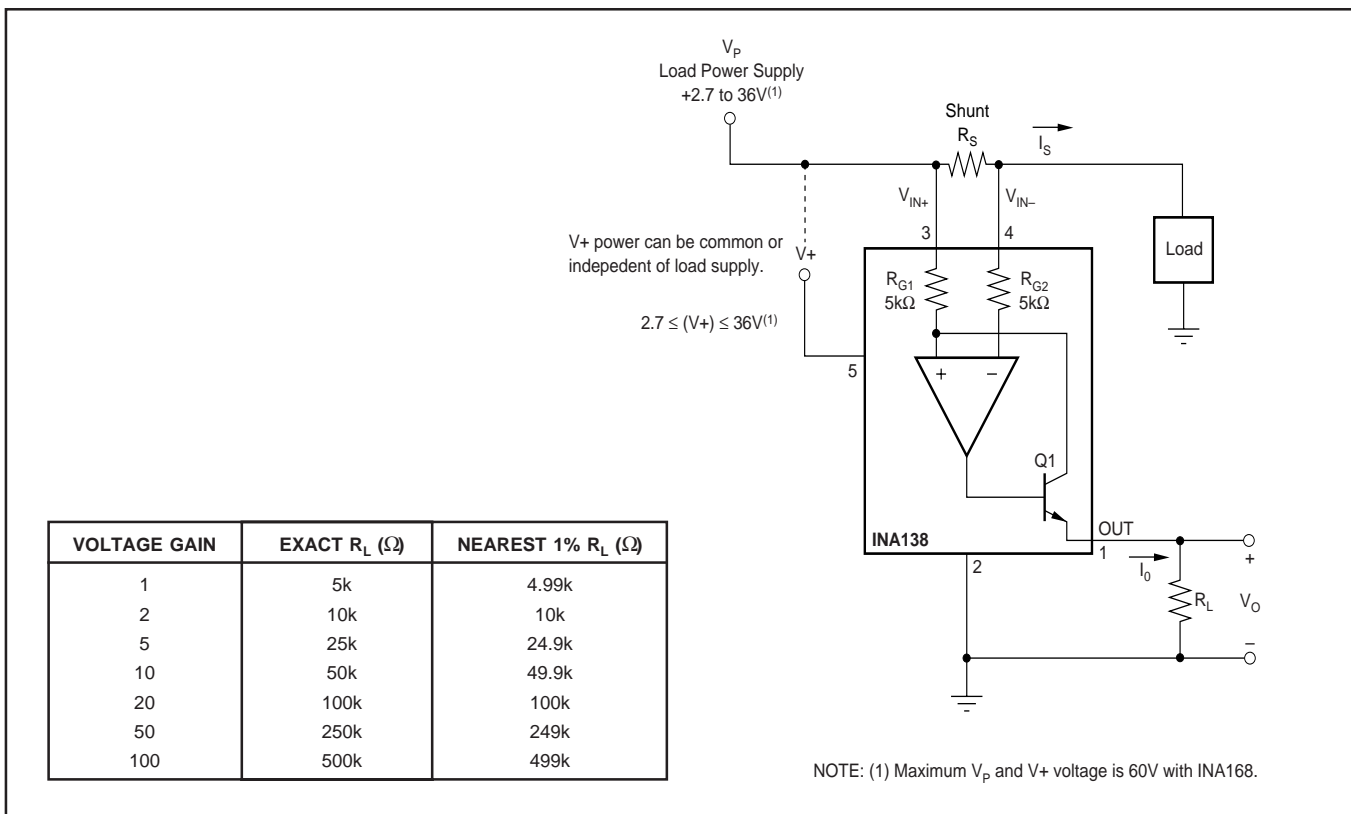


FIGURE 1. Basic Circuit Connections.

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. Figure 1 shows the recommended values of  $R_L$ .

## OUTPUT VOLTAGE RANGE

The output of the INA138 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:

$$V_{out\ max} = (V_+) - 0.7V - (V_{IN+} - V_{IN-}) \quad (3)$$

or

$$V_{out\ max} = V_{IN-} - 0.5V \quad (4)$$

(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 Characteristics). For widest possible bandwidth, keep the capacitive load on the output to a minimum. Reduction in bandwidth due to capacitive load is shown in the Typical Characteristics.

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

## APPLICATIONS

The INA138 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. A few ideas are illustrated in Figures 2 through 7.

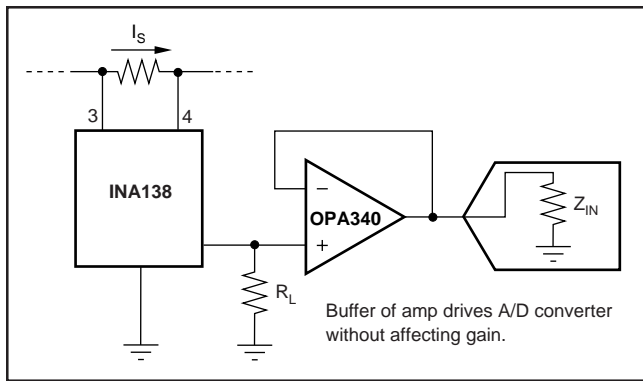


FIGURE 2. Buffering Output to Drive an A/D Converter.

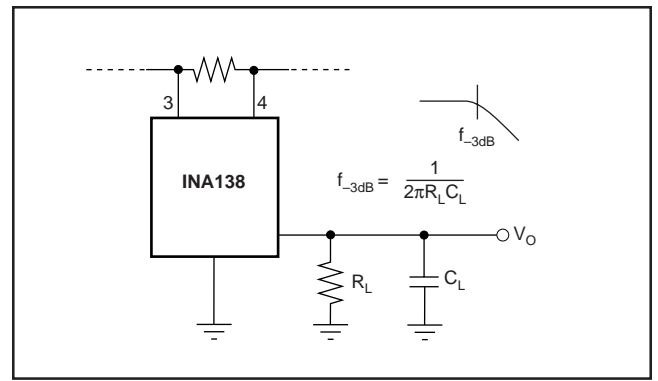


FIGURE 3. Output Filter.

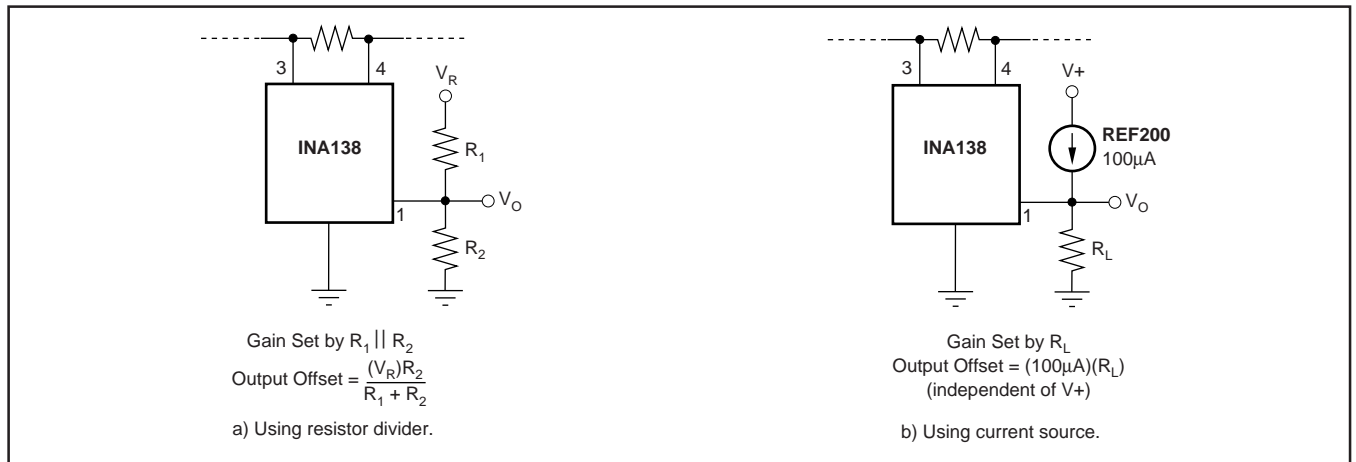


FIGURE 4. Offsetting the Output Voltage.

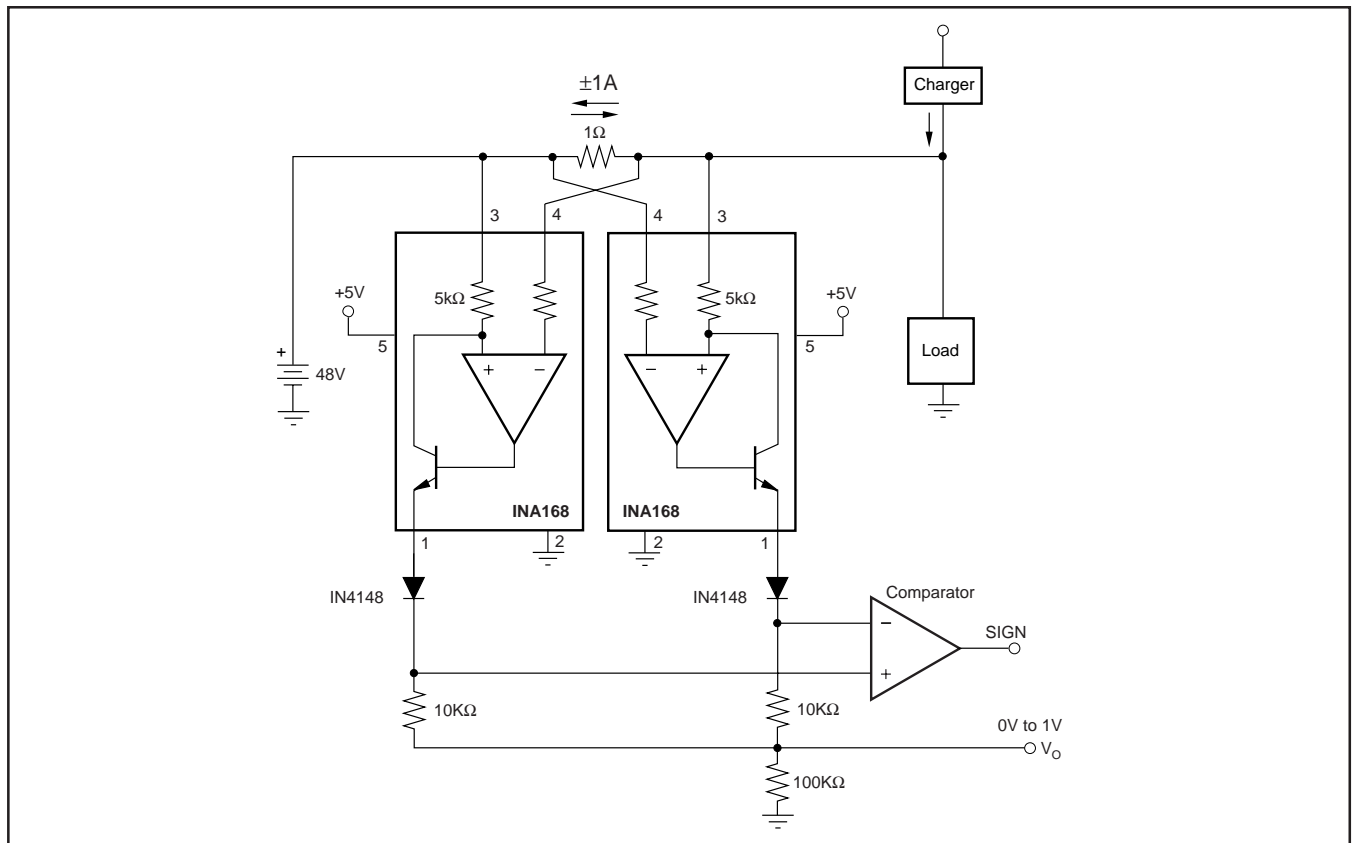


FIGURE 5. Bipolar Current Measurement.

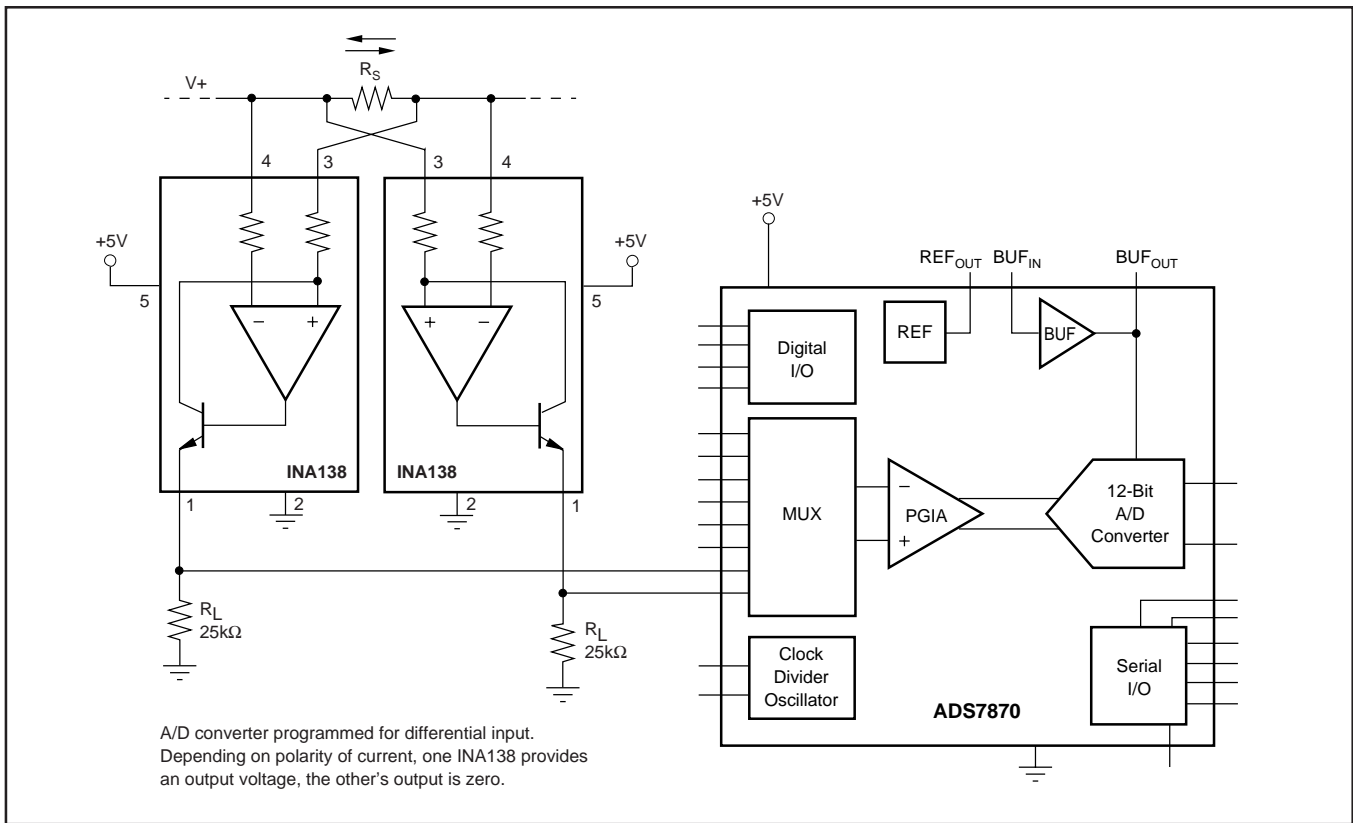


FIGURE 6. Bipolar Current Measurement Using Differential Input of A/D Converter.

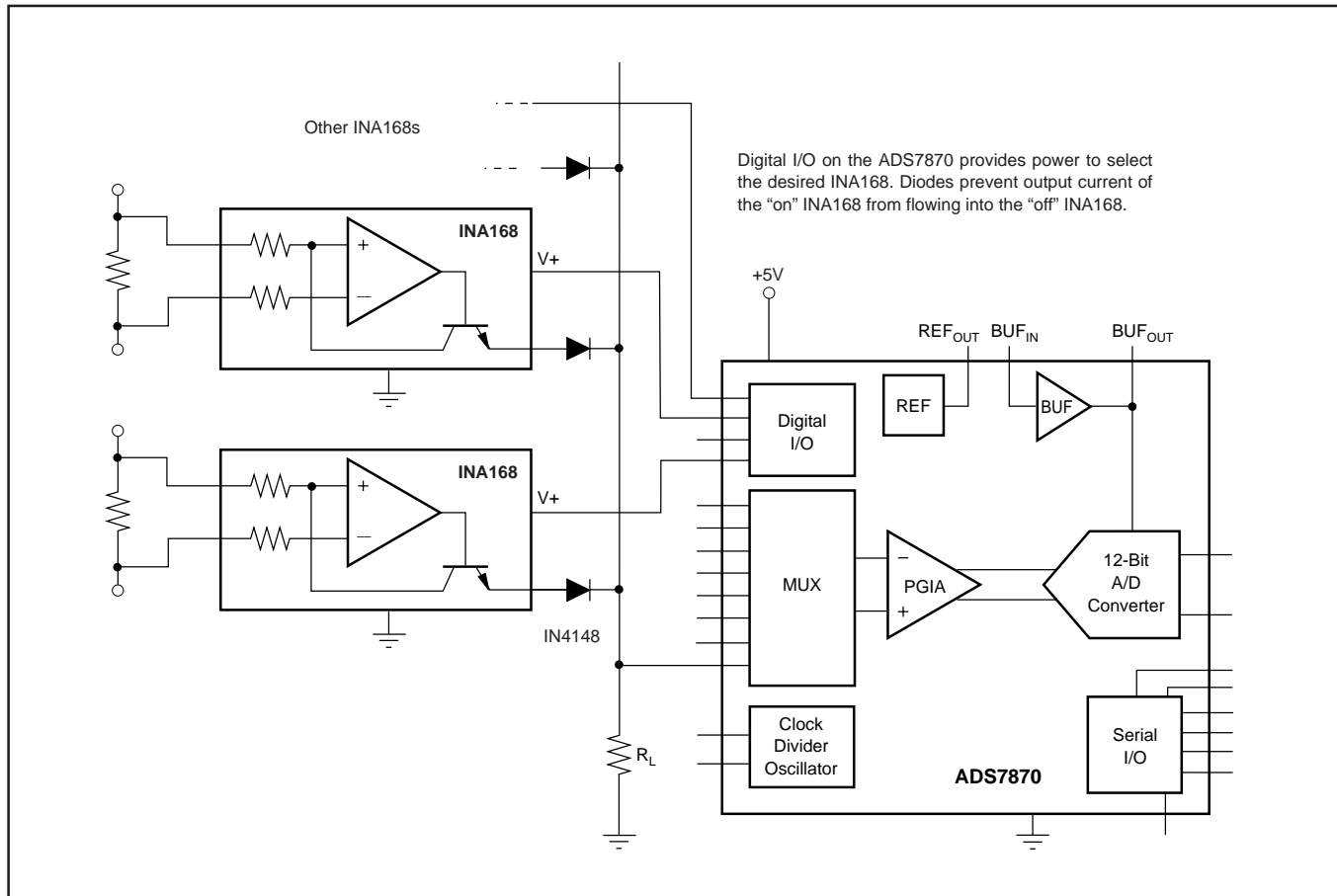


FIGURE 7. Multiplexed Measurement Using Logic Signal for Power.

---

## PACKAGING INFORMATION

ORDERABLE DEVICE	STATUS(1)	PACKAGE TYPE	PACKAGE DRAWING	PINS	PACKAGE QTY
INA138NA/250	ACTIVE	SOP	DBV	5	250
INA138NA/3K	ACTIVE	SOP	DBV	5	3000
INA168NA/250	ACTIVE	SOP	DBV	5	250
INA168NA/3K	ACTIVE	SOP	DBV	5	3000

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

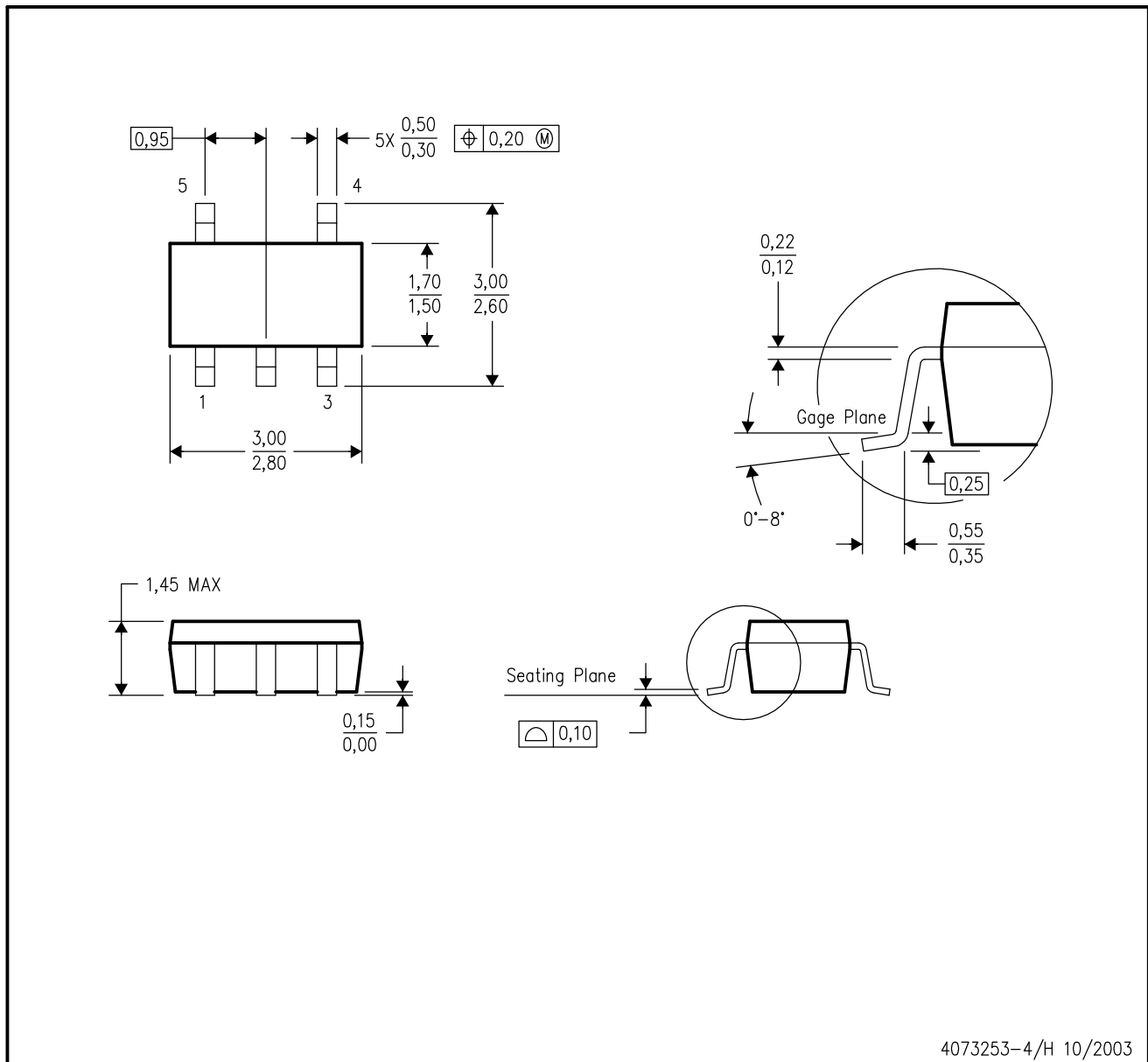
**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

---

DBV (R-PDSO-G5)

PLASTIC SMALL-OUTLINE PACKAGE



4073253-4/H 10/2003

- 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-178 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