SBOS193 – MARCH 2001

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: 75μA (typ)**
- **MSOP-8 PACKAGE**

APPLICATIONS

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

DESCRIPTION

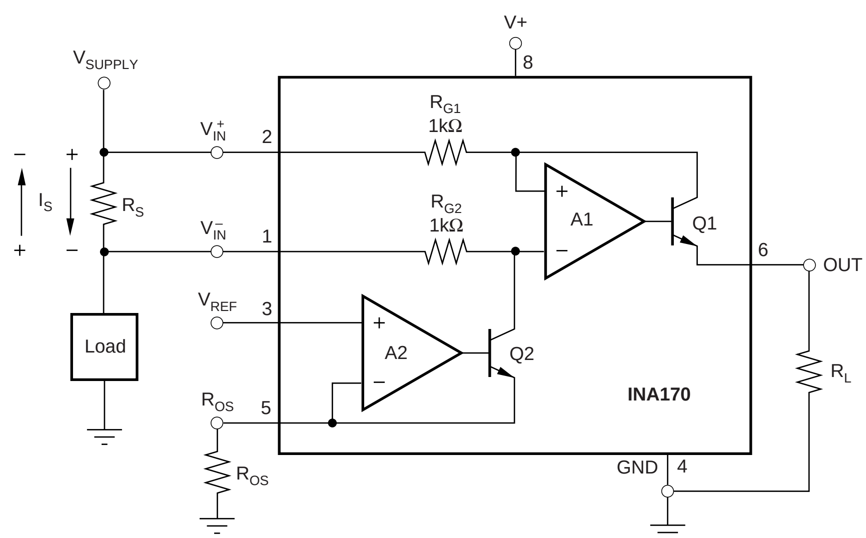
The INA170 is a high-side, bidirectional current shunt monitor featuring a wide input common-mode voltage range, low quiescent current, and a tiny MSOP-8 package.

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 10μA 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.



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PACKAGE/ORDERING INFORMATION

PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER(1)	TRANSPORT MEDIA
INA170EA	MSOP-8	337	–40°C to +85°C	INA170EA	INA170EA/250	Tape and Reel
"	"	"	"	"	INA170EA/2K5	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(1)

Supply Voltage, V+ to GND	–0.3V to 40V
Analog Inputs, Common Mode	–0.3V to 60V
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.

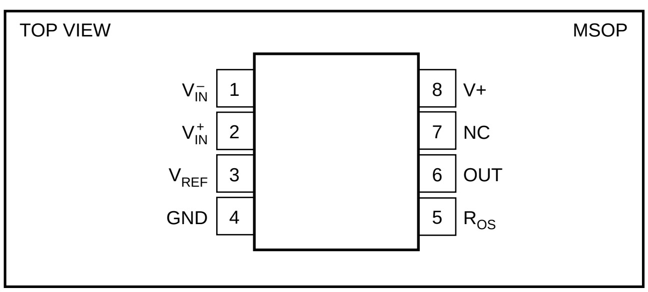
ELECTRICAL CHARACTERISTICS

At T_A = –40°C to +85°C, V_S = 5V, V_{IN}^+ = 12V, R_{OUT} = 25kΩ, unless otherwise noted.

PARAMETER	CONDITION	INA170EA			UNITS
		MIN	TYP	MAX	
INPUT					
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}^+ = +2.7V to +60V, V_{SENSE} = 50mV	100	120		dB
Offset Voltage(1) RTI			±0.2	±1	mV
vs Temperature	T_{MIN} to T_{MAX}		1		µV/°C
vs Power Supply	V+ = +2.7V to +60V, V_{SENSE} = 50mV		0.1	10	µV/V
Input Bias Current	V_{IN}^+, V_{IN}^-		10		uA
OFFSETTING AMPLIFIER					
Offsetting Equation	$V_{OS} = (R_L/R_{OS})\ V_{REF}$				
Input Voltage		1		V_S – 1	V
Input Offset Voltage			±0.2	±1	mV
vs Temperature	T_{MIN} to T_{MAX}		10		µV/°C
Programming Current through R_{OS}		0		1	mA
Input Impedance			10^{10} || 4		Ω || pF
Input Bias Current	V_{IN}^+, V_{IN}^-		+10		nA
OUTPUT					
Transconductance	V_{SENSE} = 10mV to 150mV	0.990	1	1.01	mA/V
vs Temperature	V_{SENSE} = 100mV		50		nA/°C
Nonlinearity Error	V_{SENSE} = 10mV to 150mV		±0.01	±0.1	%
Total Output Error	V_{SENSE} = 100mV		±0.5	±2	%
Output Impedance			1 || 5		GΩ || pF
Voltage Output					
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
FREQUENCY RESPONSE					
Bandwidth	R_{OUT} = 10kΩ		400		kHz
Settling Time (0.1%)	5V Step, R_{OUT} = 10kΩ		3		µs
NOISE					
Output-Current Noise Density			20		$pA/\sqrt{Hz}$
Total Output-Current Noise	BW = 100kHz		7		nA RMS
POWER SUPPLY					
Operating Range	V+	+2.7		+60	V
Quiescent Current	V_{SENSE} = 0, I_O = 0		75	125	µA
TEMPERATURE RANGE					
Specification, T_{MIN} to T_{MAX}		–40		85	°C
Operating		–55		125	°C
Storage		–65		150	°C
Thermal Resistance, θ_{JA}			150		°C/W

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

PIN CONFIGURATION

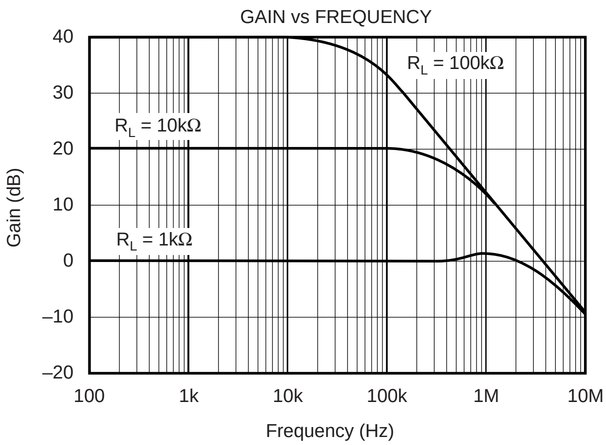


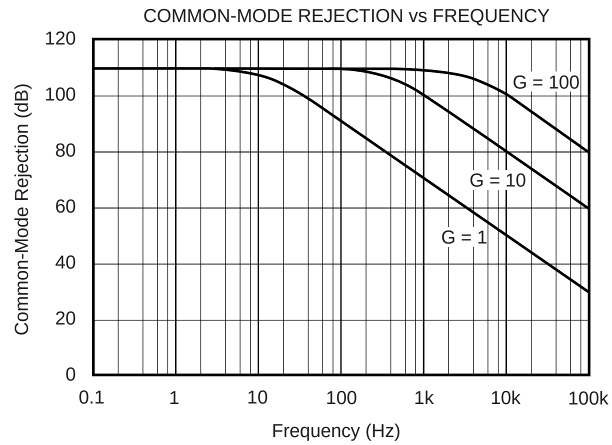
PIN DESCRIPTION

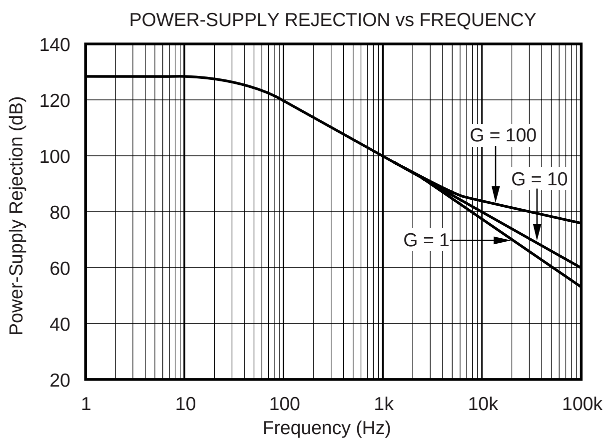
PIN	DESIGNATOR	DESCRIPTION
1	V_{IN}^+	Noninverting Input
2	V_{IN}^-	Inverting Input
3	V_{REF}	Reference Voltage Input
4	GND	Ground
5	R_{OS}	Offset Resistor
6	OUT	Output
7	NC	No Connection
8	V+	Supply Voltage

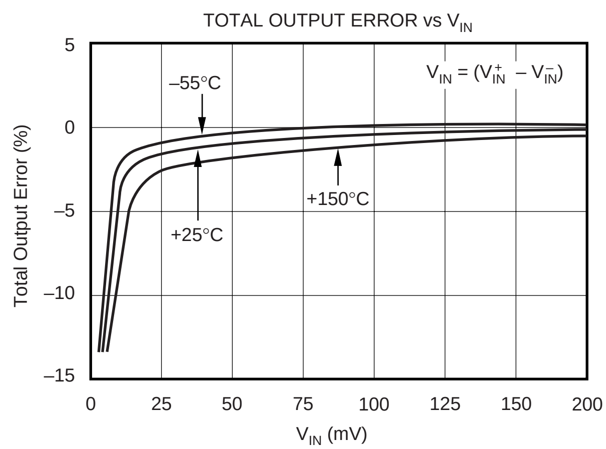
TYPICAL CHARACTERISTICS

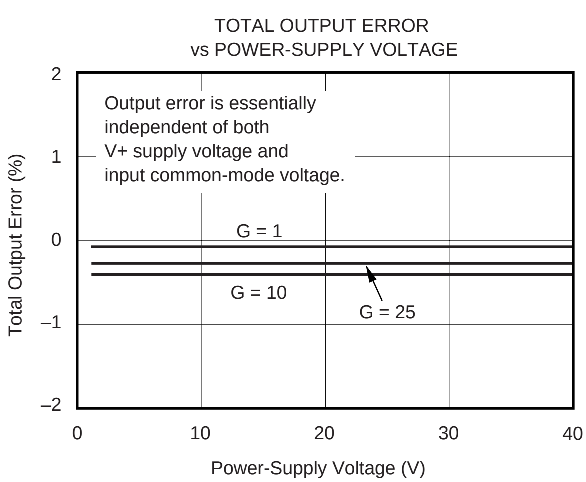
At $T_A = +25°C$, V+ = 5V, $V_{IN}^{+} = 12V$, $R_L = 25k\Omega$, unless otherwise noted.

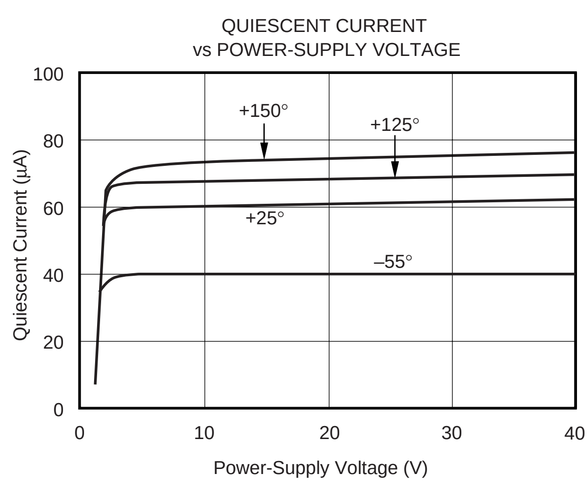








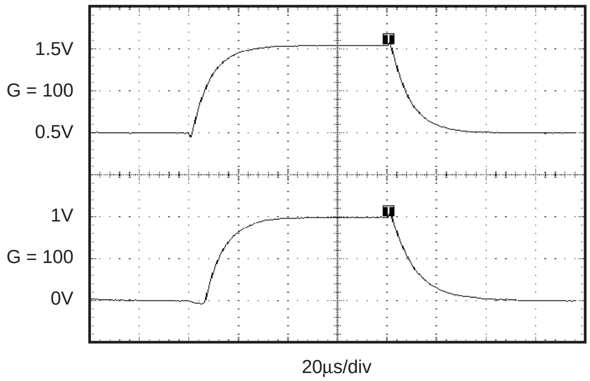




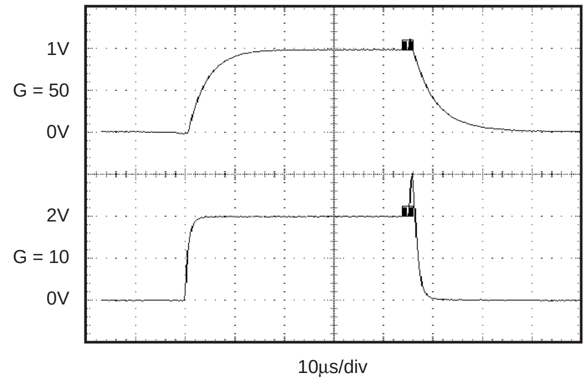
TYPICAL CHARACTERISTICS (Cont.)

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

STEP RESPONSE



STEP RESPONSE



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:

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

$$\text{where } g_m = 1000\mu A/V \tag{2}$$

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

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

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:

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

The maximum differential input voltage for accurate measurements is 0.5V, which produces a 500µA 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.

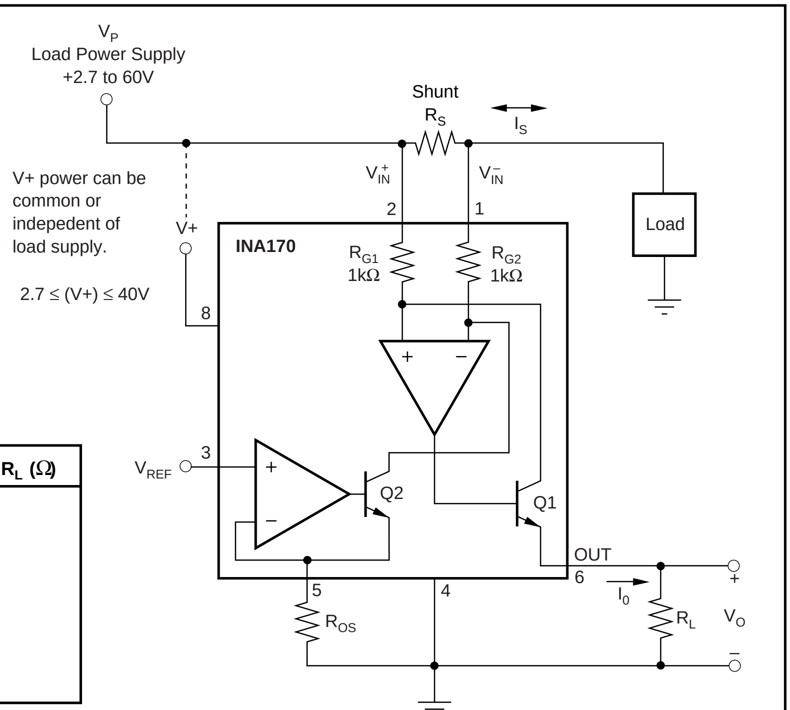
No power-supply bypass capacitors are required for stability of the INA170. However, applications with noisy or high impedance power supplies may require de-coupling capacitors to reject power-supply noise. Connect bypass capacitors close to the device pins.

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



VOLTAGE GAIN	EXACT R_L (Ω)	NEAREST 1% R_L (Ω)
1	1k	1k
2	2k	2k
5	5k	4.99k
10	10k	10k
20	20k	20k
50	50k	49k
100	100k	100k

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 100kΩ 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.

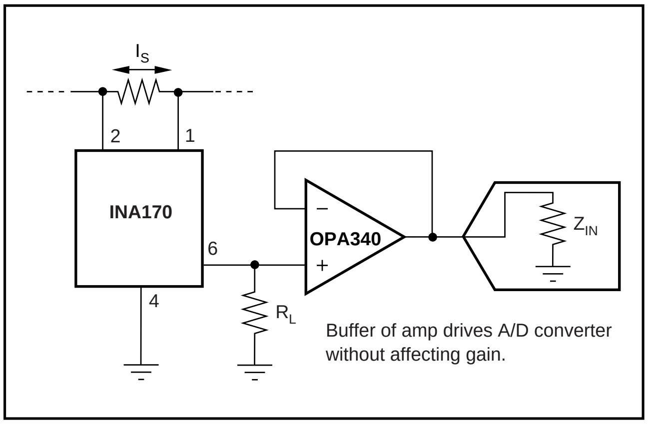


FIGURE 2. Buffering Output to Drive A/D Converter.

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.

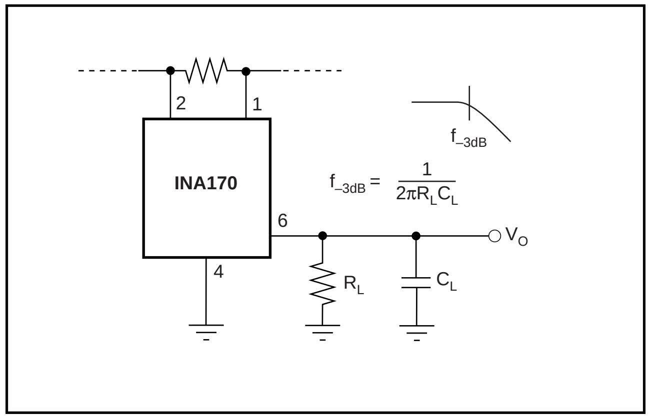


FIGURE 3. Output Filter.

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.

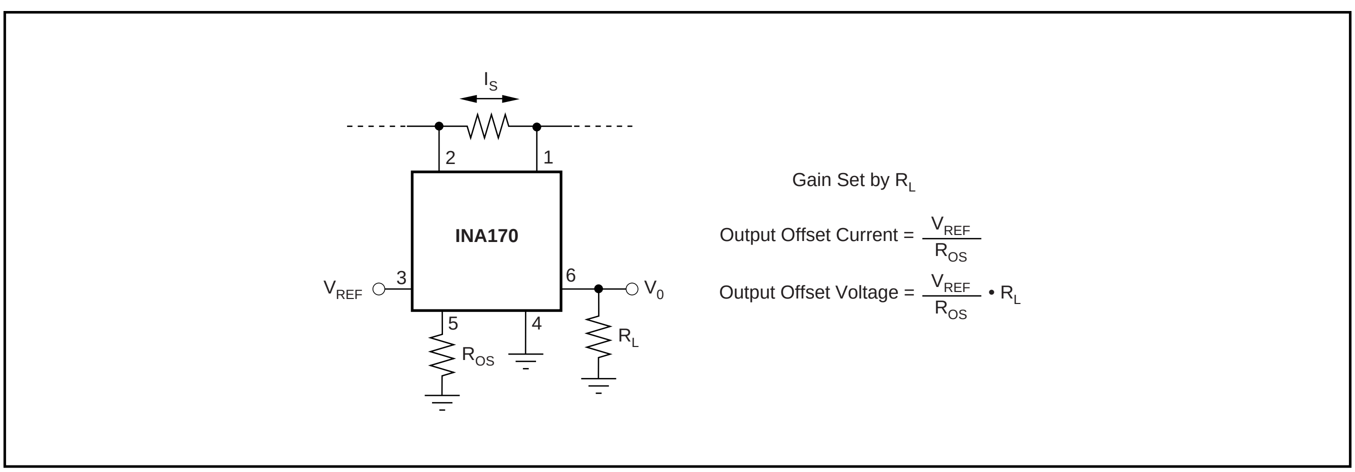


FIGURE 4. Offsetting the Output Voltage.

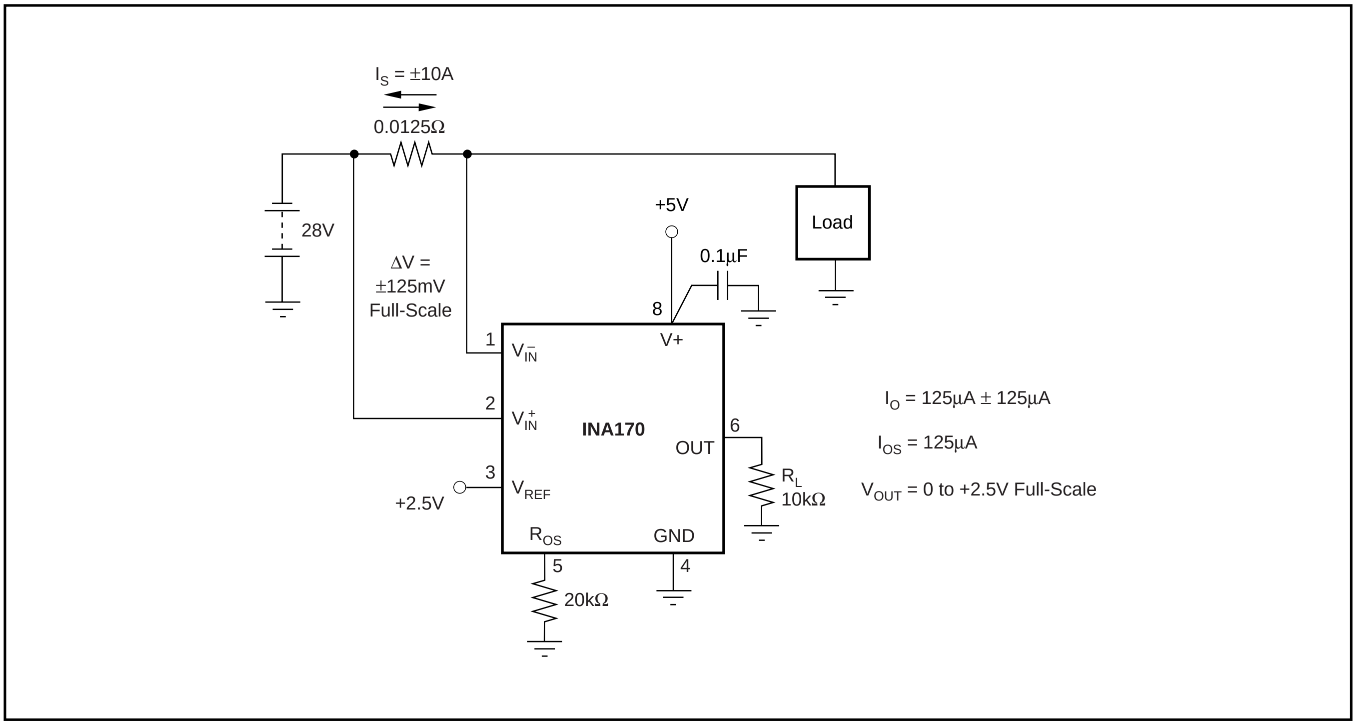


FIGURE 5. Bipolar Current Measurement.

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