

## Precision 76V High-Side Current Sense Amplifiers with Voltage Output

### General Description

The LMP8480 and LMP8481 are precision high-side current sense amplifiers that amplify a small differential voltage developed across a current sense resistor in the presence of high input common-mode voltages.

These amplifiers are designed for bidirectional (LMP8481) or unidirectional (LMP8480) current applications and will accept input signals with common-mode voltage range from 4V to 76V with a bandwidth of 270 kHz.

Since the operating power supply range overlaps the input common mode voltage range, the LMP848x can be powered by the same voltage that is being monitored. This benefit eliminates the need for an intermediate supply voltage to be routed to the point of load where the current is being monitored, resulting in reduced component count and board space.

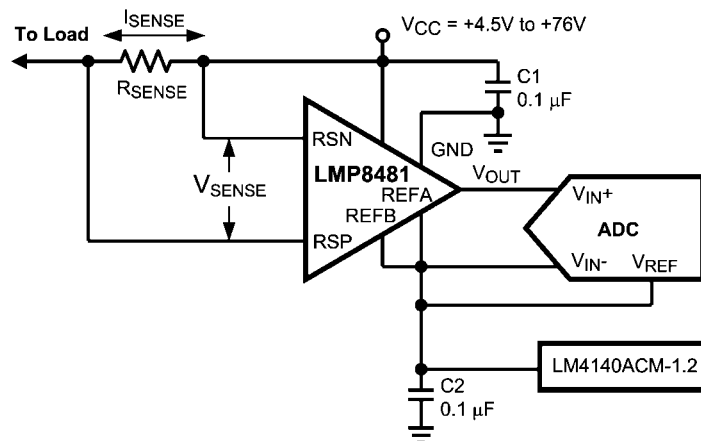
The LMP848x family consists of fixed gains of 20, 50, 60 and 100 for applications that demand high accuracy over temperature. The low input offset voltage allows the use of smaller sense resistors without sacrificing system error.

The wide operating temperature range of -40C to 125C makes the LMP848x an ideal choice for automotive, telecommunications, industrial, and consumer applications.

The LMP8480 and LMP8481 are pin for pin replacements for the MAX4080 and MAX4081, offering improved offset voltage, wider reference adjust range and higher output drive capabilities.

The LMP8480 and LMP8481 are available in a 8-pin MSOP package and the LMP8481 is also available in a 8-pad LLP.

### Typical Application



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### Features

Typical values,  $T_A = 25^\circ\text{C}$

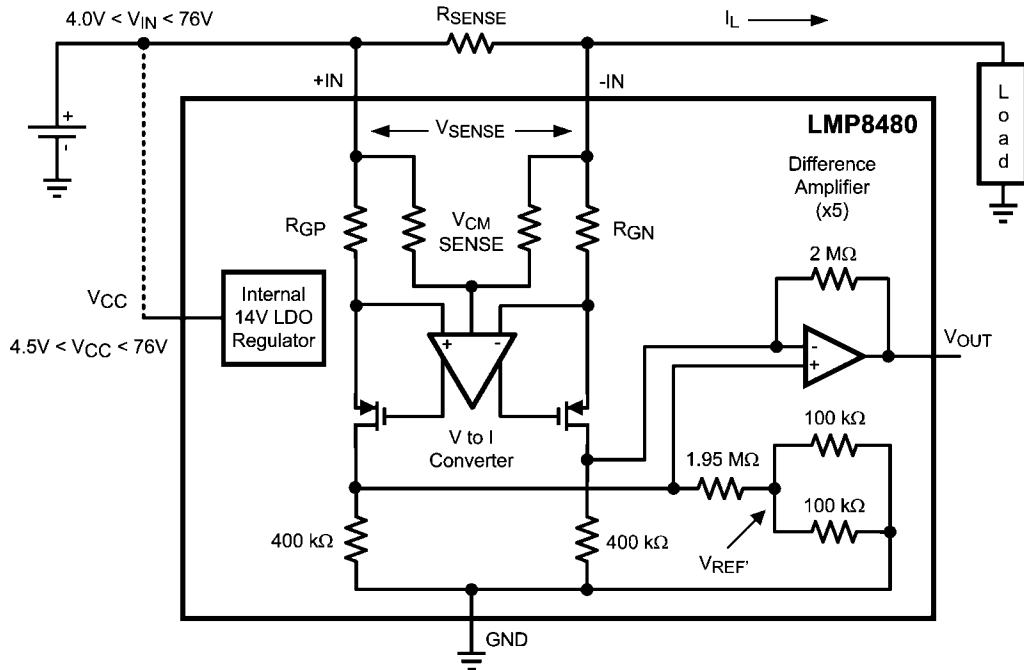
- Bi-Directional or Uni-Directional Sensing
- Common Mode Voltage Range 4.0V to 76V
- Supply Voltage Range 4.5V to 76V
- Fixed Gains 20, 50, 60 and 100 V/V
- Gain Accuracy  $\pm 0.1\%$
- Offset  $\pm 80\mu\text{V}$
- Bandwidth (-3dB) 270KHz
- Quiescent Current  $< 100\mu\text{A}$
- Buffered High-Current Output  $> 5\text{mA}$
- Input Bias Current  $7\mu\text{A}$
- PSRR (DC) 122dB
- CMRR (DC) 124dB
- Temperature Range -40 to  $+125^\circ\text{C}$
- MSOP-8 or LLP-8 Packages

### Applications

- High-side current sense
- Vehicle current measurement
- Telecommunications
- Motor controls
- Laser or LED Drivers
- Energy Management
- Solar Panel Monitoring

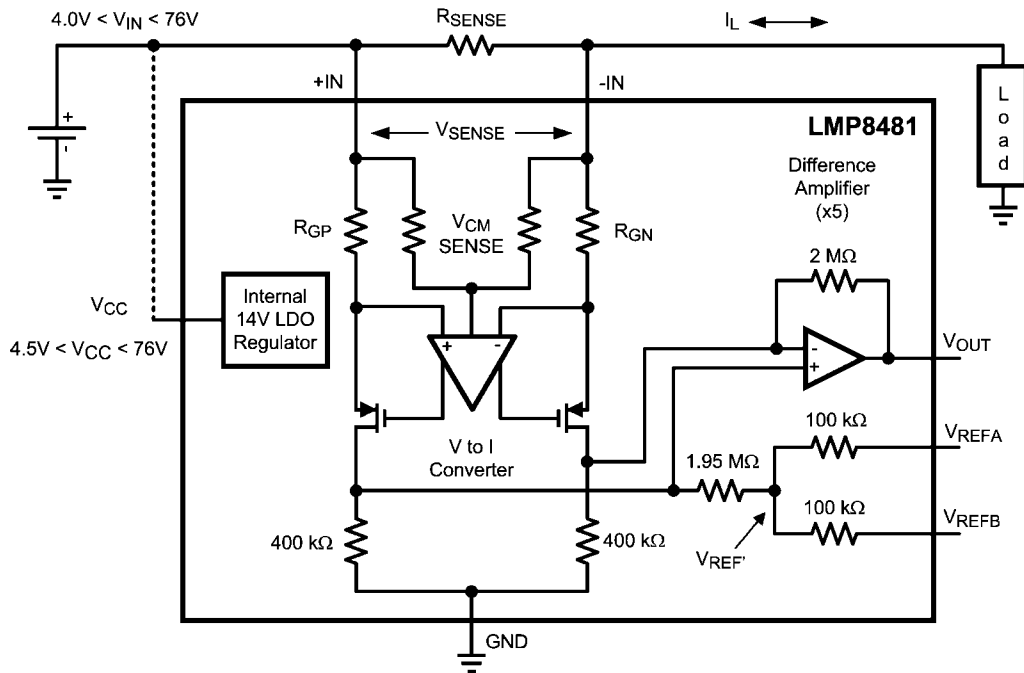
## Block Diagrams

LMP8480 Block Diagram



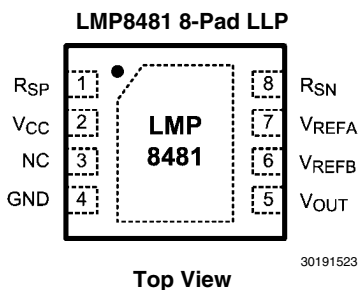
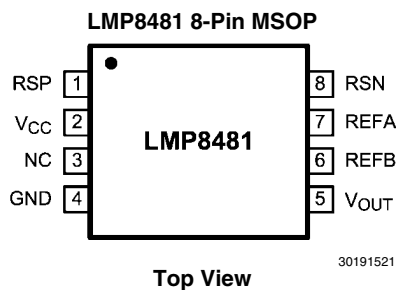
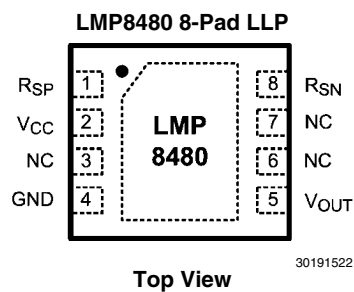
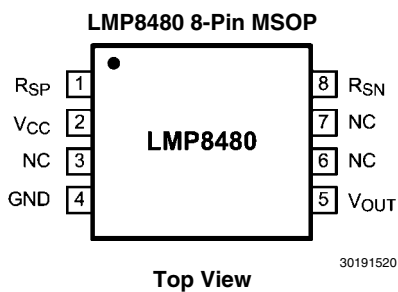
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LMP8481 Block Diagram



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## Connection Diagrams



## Pin Descriptions

Pin	Name	Description
1	$R_{SP}$	Positive current sense input
2	$V_{CC}$	Positive supply voltage
3	NC	No Connection – Not internally Connected.
4	GND	Ground
5	$V_{OUT}$	Output
6	NC or $R_{EFA}$	LMP8480: No Connection      LMP8481: Reference Voltage "B" Input
7	NC or $R_{EFB}$	LMP8480: No Connection      LMP8481: Reference Voltage "A" Input
8	$R_{SN}$	Negative current sense input

## Ordering Information

Package	Gain	Sensing	Part Number	Marking	Transport Media	NSC Drawing
8-Pin MSOP	20 V/V	Unidirectional	LMP8480MM-T *	AV8A	1k Units Tape and Reel	MUA08A
			LMP8480MME-T *		250 Units Tape and Reel	
			LMP8480MMX-T *		3k Units Tape and Reel	
		Bidirectional	LMP8481MM-T *	AT9A	1k Units Tape and Reel	
			LMP8481MME-T *		250 Units Tape and Reel	
			LMP8481MMX-T *		3k Units Tape and Reel	
	50 V/V	Unidirectional	LMP8480MM-F *	AX8A	1k Units Tape and Reel	
			LMP8480MME-F *		250 Units Tape and Reel	
			LMP8480MMX-F *		3k Units Tape and Reel	
		Bidirectional	LMP8481MM-F *	AF9A	1k Units Tape and Reel	
			LMP8481MME-F *		250 Units Tape and Reel	
			LMP8481MMX-F *		3k Units Tape and Reel	
	60 V/V	Unidirectional	LMP8480MM-S	AY8A	1k Units Tape and Reel	
			LMP8480MME-S		250 Units Tape and Reel	
			LMP8480MMX-S		3k Units Tape and Reel	
		Bidirectional	LMP8481MM-S *	AA9A	1k Units Tape and Reel	
			LMP8481MME-S *		250 Units Tape and Reel	
			LMP8481MMX-S *		3k Units Tape and Reel	
	100 V/V	Unidirectional	LMP8480MM-H *	AZ8A	1k Units Tape and Reel	
			LMP8480MME-H *		250 Units Tape and Reel	
			LMP8480MMX-H *		3k Units Tape and Reel	
		Bidirectional	LMP8481MM-H *	AH9A	1k Units Tape and Reel	
			LMP8481MME-H *		250 Units Tape and Reel	
			LMP8481MMX-H *		3k Units Tape and Reel	

Package	Gain	Sensing	Part Number	Marking	Transport Media	NSC Drawing
8 Pad LLP	20 V/V	Unidirectional	LMP8480SD-T *	8480T	1k Units Tape and Reel	SDA08A
			LMP8480SDE-T *		250 Units Tape and Reel	
			LMP8480SDX-T *		3k Units Tape and Reel	
		Bidirectional	LMP8481SD-T *	8481T	1k Units Tape and Reel	
			LMP8481SDE-T *		250 Units Tape and Reel	
			LMP8481SDX-T *		3k Units Tape and Reel	
	50 V/V	Unidirectional	LMP8480SD-F *	8480F	1k Units Tape and Reel	
			LMP8480SDE-F *		250 Units Tape and Reel	
			LMP8480SDX-F *		3k Units Tape and Reel	
		Bidirectional	LMP8481SD-F *	8481F	1k Units Tape and Reel	
			LMP8481SDE-F *		250 Units Tape and Reel	
			LMP8481SDX-F *		3k Units Tape and Reel	
	60 V/V	Unidirectional	LMP8480SD-S *	8480S	1k Units Tape and Reel	
			LMP8480SDE-S *		250 Units Tape and Reel	
			LMP8480SDX-S *		3k Units Tape and Reel	
		Bidirectional	LMP8481SD-S *	8481S	1k Units Tape and Reel	
			LMP8481SDE-S *		250 Units Tape and Reel	
			LMP8481SDX-S *		3k Units Tape and Reel	
	100V/V	Unidirectional	LMP8480SD-H *	8480H	1k Units Tape and Reel	
			LMP8480SDE-H *		250 Units Tape and Reel	
			LMP8480SDX-H *		3k Units Tape and Reel	
		Bidirectional	LMP8481SD-H *	8481H	1k Units Tape and Reel	
			LMP8481SDE-H *		250 Units Tape and Reel	
			LMP8481SDX-H *		3k Units Tape and Reel	

Devices with an asterisk (\*) are future products. Please contact the factory for availability.

## Absolute Maximum Ratings *(Note 1)*

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

Over operating free-air temperature range (unless otherwise noted).

		LMP8480, LMP8481	UNIT
Supply Voltage ( $V_{CC}$ to GND)		-0.3 to +85	V
$R_{SP}$ or $R_{SN}$ to GND		-0.3 to +85	V
$V_{OUT}$ to GND		-0.3 to the lesser of ( $V_{CC} + 0.3$ ) or +20	V
$V_{REF}$ Pins (LMP8481 Only)	Other $V_{REF}$ pin tied to ground	-0.3 to +12	V
	Applied to both $V_{REF}$ Pins tied together	-0.3 to +6	V
Differential Input Voltage		±85	V
Current into output pin		±20 <i>(Note 12)</i>	mA
Current into any other pins		±5 <i>(Note 12)</i>	mA
Operating Temperature		-40 to +125	°C
Storage Temperature		-65° to +150	°C
Junction Temperature		+150	°C
Package Thermal Resistance ( $\theta_{JA}$ )	MSOP-8	185	°C/W
	LLP-8	70	°C/W
ESD Ratings	Human Body Model (HBM)	2000	V
	Charged Device Model (CDM)	750	V

## Recommended Operating Ratings

Expected normal operating conditions over free-air temperature range (unless otherwise noted).

		LMP8480, LMP8481	UNIT
Supply Voltage ( $V_{CC}$ )		+4.5V to +76	V
Common Mode Voltage		+4.0V to +76	V
Differential Input Voltage ( $V_{SENSE}$ )		±667	mV
Reference Input (LMP8481 Only)	$V_{REFA}$ and $V_{REFB}$ tied together	-0.3 to the lesser of ( $V_{CC} - 1.5$ ) or +6	V
	Single $V_{REF}$ pin with other $V_{REF}$ pin grounded	-0.3 to +12, or where the average of the two $V_{REF}$ pins is less than the lesser of ( $V_{CC} - 1.5$ ) or +6	V

## Electrical Characteristics (Note 5)

Unless otherwise specified, all limits guaranteed for at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = +4.5\text{V}$  to  $+76\text{V}$ ,  $+4.5\text{V} < V_{CM} < +76\text{V}$ ,  $R_L = 100\text{k}$ ,  $V_{SENSE} = (V_{RSP} - V_{RSN}) = 0\text{V}$ . **Boldface** limits apply at the temperature extremes,  $T_{MIN}$   $T_A$   $T_{MAX}$ .

Parameter	Condition		Min <small>(Note 7)</small>	Typ <small>(Note 6)</small>	Max <small>(Note 7)</small>	Units	
Input Offset Voltage (RTI)	$V_{OS}$	$V_{CC} = V_{RSP} = 48\text{V}$ , $\Delta V_{SENSE} = 100\text{mV}$	$T_a = +25^\circ\text{C}$	$\pm 80$	$\pm 265$	$\mu\text{V}$	
			$T_a = -40^\circ\text{C}$ to $+125^\circ\text{C}$		<b><math>\pm 900</math></b>		
Input Offset Voltage Drift <small>(Note 8)</small>	$TCV_{OS}$			6		$\mu\text{V}/^\circ\text{C}$	
Input Bias Current <small>(Note 11)</small>	$I_B$	$V_{CC} = V_{RSP} = 76\text{V}$ , Per Input		6.3	<b>12</b>	$\mu\text{A}$	
Input Leakage Current	$I_{LEAK}$	$V_{CC} = 0$ , $V_{RSP} = 76\text{V}$ , Both Inputs Together		0.01	<b>2</b>	$\mu\text{A}$	
Differential Input Voltage Across Sense Resistor <small>(Note 10)</small>	$V_{SENSE}$ (MAX)	$V_{CC} = 16$	-T Version		<b>667</b>	mV	
			-F Version		<b>267</b>		
			-S Version		<b>222</b>		
			-H Version		<b>133</b>		
Gain	$A_V$		-T Version	<b>19.8</b>	20	<b>20.2</b>	V/V
			-F Version	<b>49.6</b>	50	<b>50.4</b>	
			-S Version	<b>59.5</b>	60	<b>60.5</b>	
			-H Version	<b>99.2</b>	100	<b>100.8</b>	
Gain Error		$V_{CC} = V_{RSP} = 48\text{V}$	$T_a = +25^\circ\text{C}$		$\pm 0.6$	%	
			$T_a = -40^\circ\text{C}$ to $+125^\circ\text{C}$		<b><math>\pm 0.8</math></b>	%	
DC Power Supply Rejection Ratio	DC PSRR	$V_{RSP} = 48\text{V}$ , $V_{CC} = 4.5$ to $76\text{V}$		<b>100</b>	122		dB
DC Common Mode Rejection Ratio	DC	$V_{CC} = 48\text{V}$ , $V_{RSP} = 4.5$ to $76\text{V}$		<b>100</b>	124		dB
	CMRR	$V_{CC} = 48\text{V}$ , $V_{RSP} = 4$ to $76\text{V}$			124		dB
Input Common Mode Voltage Range	CMVR	CMRR > 100dB		<b>4</b>		<b>76</b>	V
Output Resistance / Load Regulation	$R_{OUT}$	$V_{SENSE} = 100\text{mV}$			0.1		
Maximum Output Voltage (Headroom) $(V_{OMAX} = V_{CC} - V_{OUT})$	$V_{OMAX}$	$V_{CC} = 4.5\text{V}$ , $V_{RSP} = 48\text{V}$ , $V_{SENSE} = +1\text{V}$ $I_{OUT}$ (sourcing) = $500\mu\text{A}$			230	500	mV
Minimum Output Voltage	$V_{OMIN}$		$V_{CC} = V_{RSP} = 48\text{V}$ , $V_{SENSE} = -1\text{V}$ , $I_{OUT}$ (sinking) = $10\mu\text{A}$		3	<b>15</b>	mV
			$V_{CC} = V_{RSP} = 4.5\text{V}$ , $V_{SENSE} = -1\text{V}$ , $I_{OUT}$ (sinking) = $10\mu\text{A}$		3		
			$V_{CC} = V_{RSP} = 48\text{V}$ , $V_{SENSE} = -1\text{V}$ , $I_{OUT}$ (sinking) = $100\mu\text{A}$		18	<b>55</b>	
			$V_{CC} = V_{RSP} = 4.5\text{V}$ , $V_{SENSE} = -1\text{V}$ , $I_{OUT}$ (sinking) = $100\mu\text{A}$		18		
Output voltage with load	$V_{OLOAD}$	$V_{CC}=28\text{V}$ , $V_{RSP}=28\text{V}$ , $V_{SENSE}=600\text{mV}$ , $I_{OUT}$ (sourcing)= $500\mu\text{A}$			12		V
Output Load Regulation	$V_{OLREG}$	$V_{CC} = 20$ , $V_{RSP} = 16$ , $V_{OUT} = 12$ , $\Delta I_L = 200\text{na}$ to $8\text{mA}$			0.001		%
Supply Current	$I_{CC}$	$V_{OUT}=2\text{V}$ , $R_L = 10\text{M}$ , $V_{CC}= V_{RSP} = 76\text{V}$			88	<b>155</b>	$\mu\text{A}$
-3 dB Bandwidth	BW	$R_L = 10\text{M}$ , $C_L = 20\text{pF}$			270		kHz
Slew Rate <small>(Note 9)</small>	SR	$V_{SENSE}$ from $10\text{mV}$ to $80\text{mV}$ , $R_L=10\text{M}$ , $C_L=20\text{pF}$			1		$\text{V}/\mu\text{s}$
Input Referred Voltage Noise	$e_{ni}$	$f = 1\text{ kHz}$			95		$\text{nV}/\sqrt{\text{Hz}}$
Output Settling Time to 1% of Final Value	$t_{SETTLE}$	$V_{SENSE} = 10\text{mV}$ to $100\text{mV}$ and $100\text{mV}$ to $10\text{mV}$ ,			20		$\mu\text{s}$
Power-up Time	$t_{PU}$	$V_{CC} = V_{RSP} = 48\text{V}$ , $V_{SENSE} = 100\text{mV}$ , output to 1% of final value			50		$\mu\text{s}$

Parameter	Condition	Min (Note 7)	Typ (Note 6)	Max (Note 7)	Units
Saturation Recovery Time	$t_{RECOVERY}$ Output settles to 1% of final value, the device will not experience phase reversal when overdriven.		50		$\mu$ s
Max Output Capacitance Load	$C_{LOAD}$ No sustained oscillations		500		pF

**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 specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical Characteristics Tables.

**Note 2:** Exceeding the Operating Ratings for extended periods of time may effect device reliability or cause parametric shifts.

**Note 3:** Human Body Model, applicable std. MIL-STD-883, Method 3015.7. Machine Model, applicable std. JESD22-A115-A (ESD SD std. of JEDEC) Field-Induced Charge-Device Model, applicable std. JESD22-C101-C (ESD FICDM std. of JEDEC).

**Note 4:** The maximum power dissipation must be derated at elevated temperatures and is dictated by  $T_{J(MAX)}$ ,  $\theta_{JA}$ , and the ambient temperature,  $T_A$ . The maximum allowable power dissipation  $P_{DMAX} = (T_{J(MAX)} - T_A) / \theta_{JA}$  or the number given in Absolute Maximum Ratings, whichever is lower.

**Note 5:** Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that  $T_J = T_A$ . No guarantee of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ .

**Note 6:** Typical values represent the most likely parametric norm at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not guaranteed on shipped production material.

**Note 7:** All limits are guaranteed by testing, design, or statistical analysis.

**Note 8:** Offset voltage temperature drift is determined by dividing the change in  $V_{OS}$  at the temperature extremes by the total temperature change.

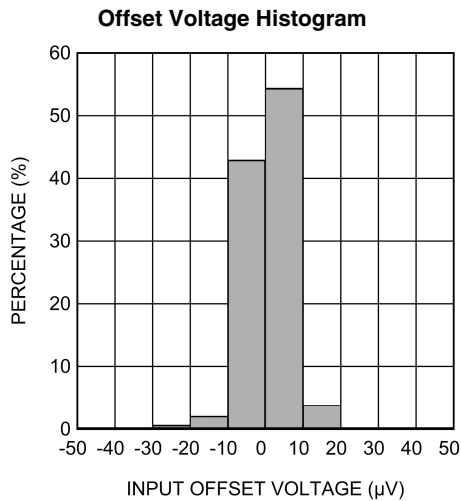
**Note 9:** The number specified is the average of rising and falling slew rates and measured at 90% to 10%.

**Note 10:** This parameter is guaranteed by design and/or characterization and is not tested in production.

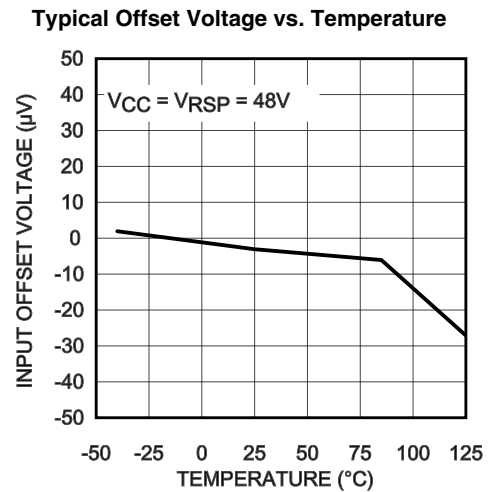
**Note 11:** Positive Bias Current corresponds to current flowing into the device.

**Note 12:** When the input voltage ( $V_{IN}$ ) at any pin exceeds power supplies ( $V_{IN} < GND$  or  $V_{IN} > V_S$ ), the current at that pin must not exceed 5mA, and the voltage ( $V_{IN}$ ) has to be within the Absolute Maximum Rating for that pin. The 20mA package input current rating limits the number of pins that can safely exceed the power supplies with current flow to four pins.

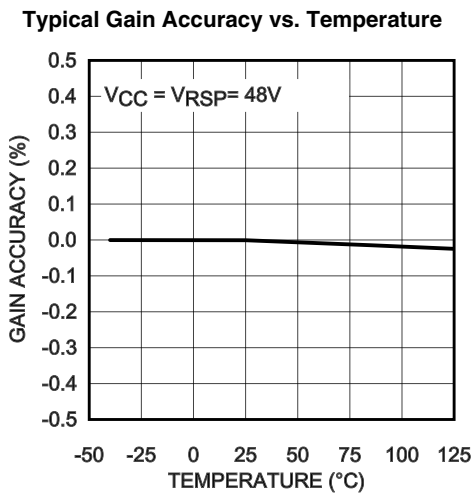
**Typical Performance Characteristics** Unless otherwise specified,  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = 4.5\text{V to } 76\text{V}$ ,  $4.5\text{V} < V_{CM} < 76\text{V}$ ,  $R_L = 100\text{k}$ ,  $V_{SENSE} = (V_{RSP} - V_{RSN}) = 0\text{V}$ , for all gain options.



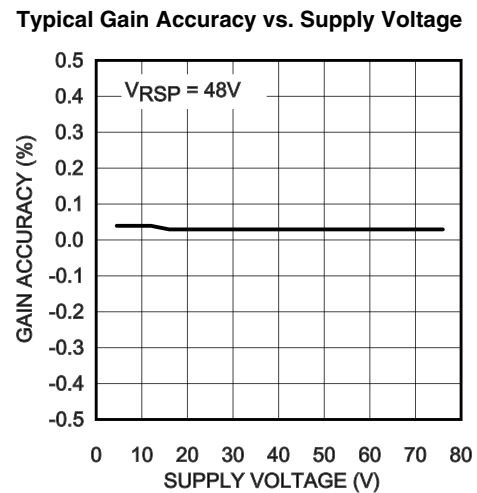
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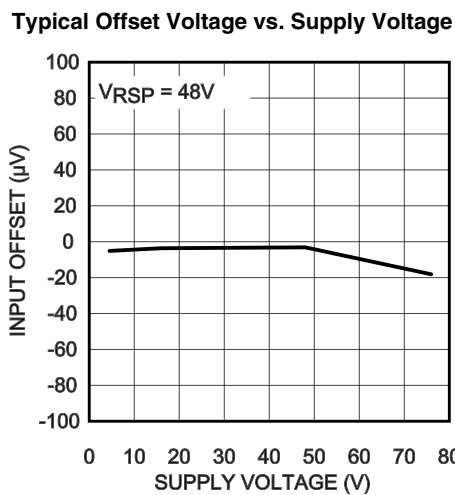
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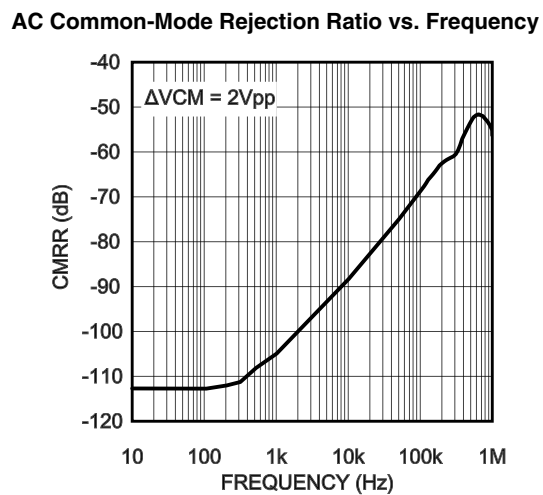
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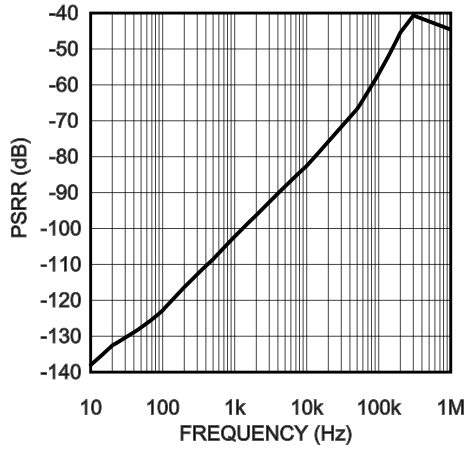


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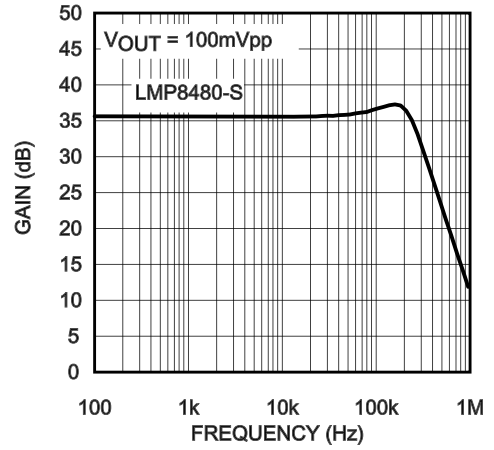
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AC Power Supply Rejection Ratio vs. Frequency



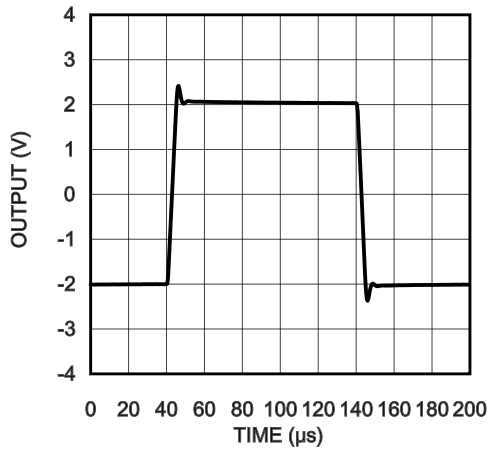
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Small Signal Gain vs. Frequency



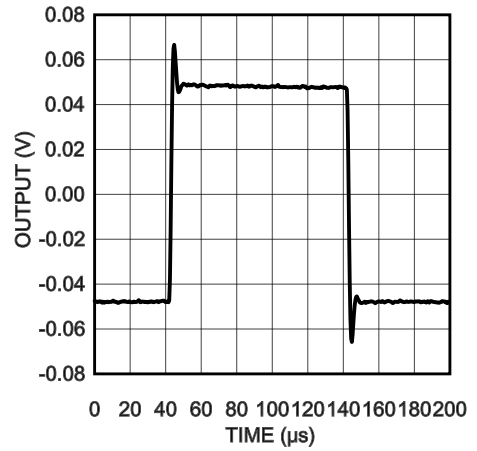
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Large Signal Pulse Response



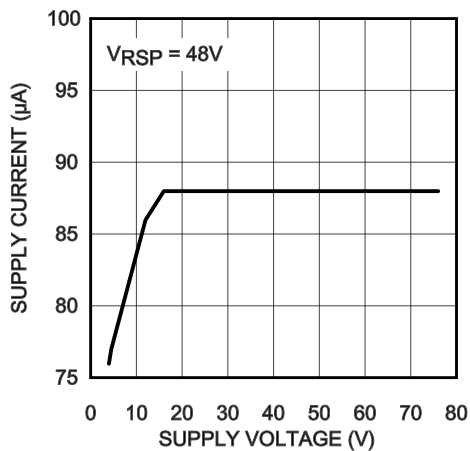
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Small Signal Pulse Response



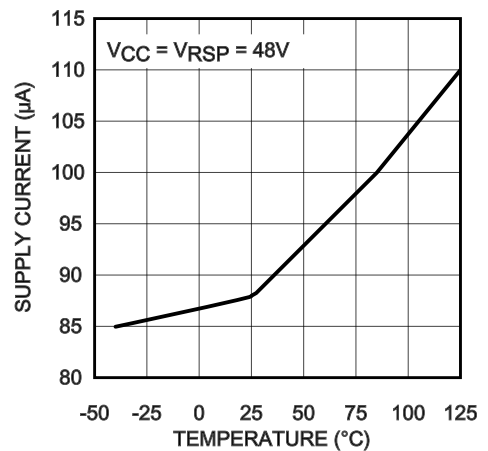
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Supply Current vs. Supply Voltage



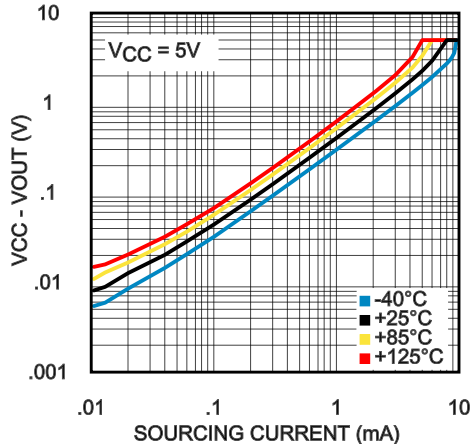
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Supply Current vs. Temperature



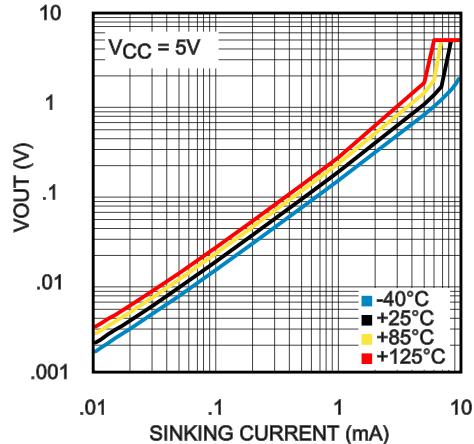
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Saturated Output Sourcing Current at 4.5V



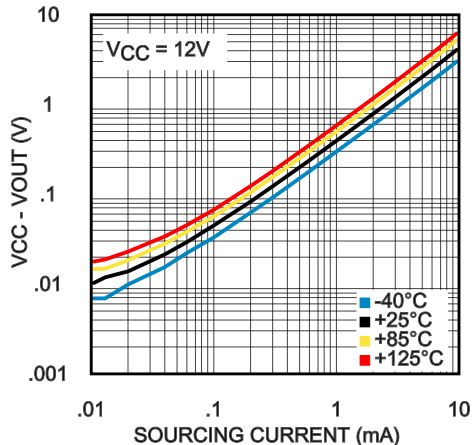
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Saturated Output Sinking Current at 4.5V



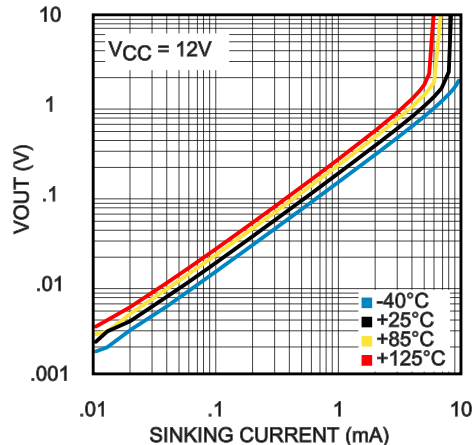
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Saturated Output Sourcing Current at 12V



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Saturated Output Current Sinking at 12V



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## Application Information

### LMP8480 AND LMP8481 INTRODUCTION

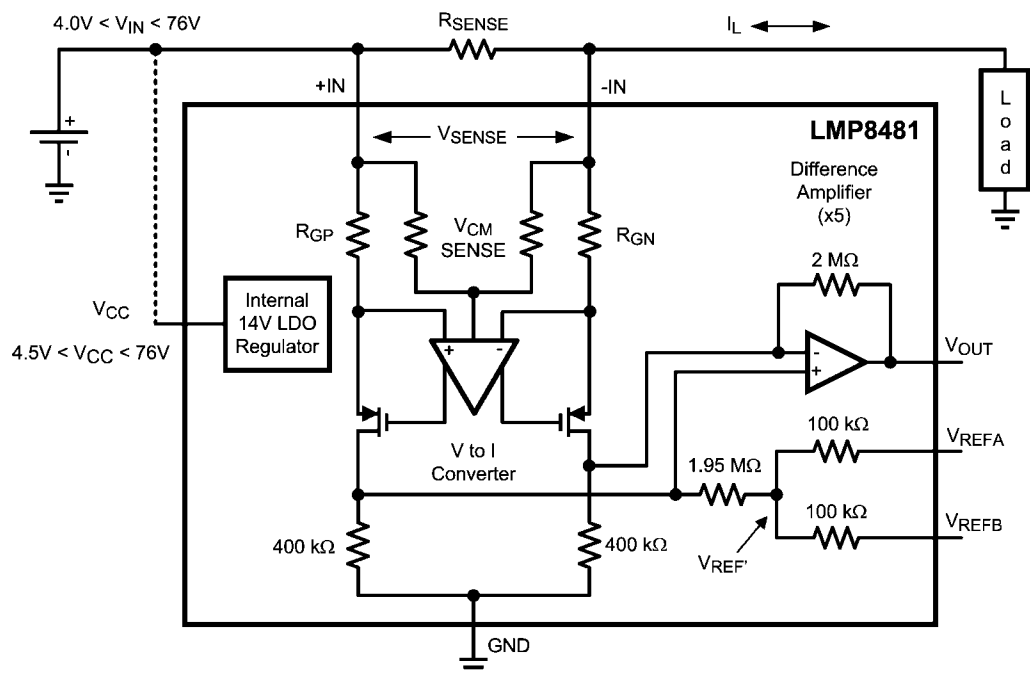
The LMP8480 and LMP8481 are single supply, high side current sense amplifiers with available fixed gains of x20, x50, x60 and x100. The power supply range is 4.5V to 76V, while the common mode input voltage range is capable of 4.0V to 76V operation. The supply voltage and common mode range are completely independent of each other. This makes the LMP848x supply voltage extremely flexible, as the LMP848x's supply voltage can be greater than, equal to, or less than the load source voltage, and allowing the device to be powered from the system supply or the load supply voltage.

The amplifier supply voltage does not have to be larger than the load source voltage. A 76V load source voltage with a 5V LMP8481 supply voltage is perfectly acceptable.

### THEORY OF OPERATION

The LMP8480 and LMP8481 are comprised of two main stages. The first stage is a differential input current to voltage converter, followed by a differential voltage amplifier and level-shifting output stage. Also present is an internal 14 Volt Low Dropout Regulator (LDO) to power the amplifiers and output stage, as well as a reference divider resistor string to allow the setting of the reference level.

As seen in [Figure 1](#), the current flowing through  $R_{SENSE}$  develops a voltage drop called  $V_{SENSE}$ . The voltage across the sense resistor,  $V_{SENSE}$ , is then applied to the input  $R_{SP}$  and  $R_{SN}$  pins of the amplifier.



30191530

**FIGURE 1. LMP8481 Functional Diagram**

Internally, the voltage on each input pin is converted to a current by the internal precision thin-film input resistors  $R_{GP}$  and  $R_{GN}$ . A second set of much higher value  $V_{CM}$  sense resistors between the inputs provide a sample of the input common mode voltage for internal use by the differential amplifier.

$V_{SENSE}$  is applied to the differential amplifier through  $R_{GP}$  and  $R_{GN}$ . These resistors change the input voltage to a differential current. The differential amplifier then servos the resistor currents through the MOSFETs to maintain a zero balance across the differential amplifier inputs.

With no input signal present, the currents in  $R_{GP}$  and  $R_{GN}$  are equal. When a signal is applied to  $V_{SENSE}$ , the current through  $R_{GP}$  and  $R_{GN}$  are imbalanced and are no longer equal. The amplifier then servos the MOSFETs to correct this current imbalance, and the extra current required to balance the input currents is then reflected down into the two lower 400kΩ "tail" resistors. The difference in the currents into the tail resistors is therefore proportional to the amplitude and polarity of  $V_{SENSE}$ . The tail resistors, being larger than the input resistors for the same current, then provide voltage gain by changing the current into a proportionally larger voltage. The gain of the first stage is then set by the tail resistor value divided by  $R_G$  value.

The differential amplifier stage then samples the voltage difference across the two 400K tail resistors and also applies a further gain-of-five and output level-shifting according to the applied reference voltage ( $V_{REF}$ ).

The resulting output of the amplifier will be equal to the differential input voltage times the gain of the device, plus any voltage value applied to the two  $V_{REF}$  pins.

The resistor values in the schematic are ideal values for clarity and understanding. The table below shows the actual values used that account for parallel combinations and loading. This table can be used for calculating the effects of any additional external resistance.

Gain Option	$R_{GP}$ and $R_{GN}$ (each)	$R_{VCMSENSE}$ (each)	$R_{TAIL}$ (each)	Differential Amp FB (each)	$V_{REFX}$ Resistors (each)
20x	98.38k	491.9k	393.52k	1967.6k	98.38k
50x	39.352k	196.76k	393.52k	1967.6k	98.38k
60x	32.793k	172.165k	393.52k	1967.6k	98.38k
100x	19.676k	98.38k	393.52k	1967.6k	98.38k

**FIGURE 2. Actual Internal Resistor Values**

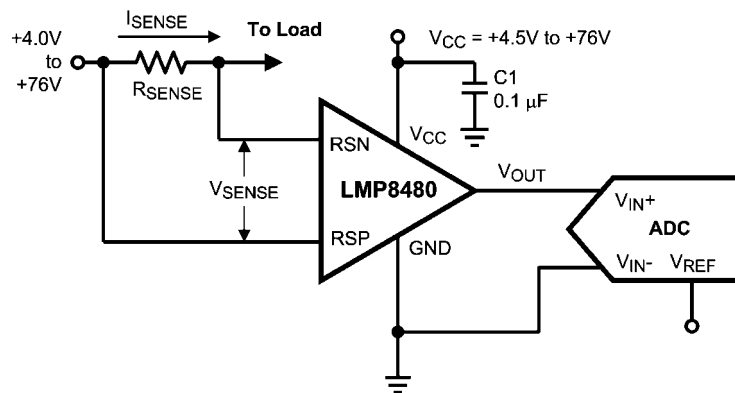
### UNI-DIRECTIONAL VS. BI-DIRECTIONAL OPERATION

**Uni-directional** operation is where the load current only flows in one direction ( $V_{SENSE}$  is always positive). Application examples would be PA monitoring, non-inductive load monitoring and laser or LED drivers. This allows the output zero reference to be true zero volts on the output. The LMP8480 is designed for unidirectional applications where the setting of  $V_{REF}$  is not required. See the [UNI-DIRECTIONAL OPERATION](#) for more details.

**Bi-directional** operation is where the load current can flow in both directions ( $V_{SENSE}$  can be positive or negative). Application examples would be battery charging or regenerative motor monitoring. The LMP8481 is designed for bidirectional applications and has a pair of  $V_{REF}$  pins to allow the setting of the output zero reference level ( $V_{REF}$ ). See the [BI-DIRECTIONAL OPERATION \(LMP8481 ONLY\)](#) section for more details.

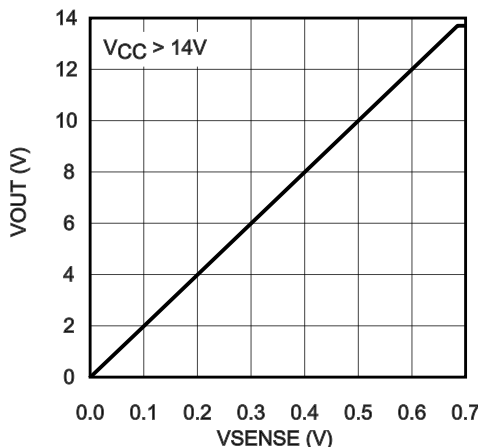
### UNI-DIRECTIONAL OPERATION

The LMP8480 is designed for unidirectional current sense applications. The output of the amplifier will be equal to the differential input voltage times the fixed device gain.



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**FIGURE 3. Uni-Directional Application with LMP8480**



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FIGURE 4. Uni-Directional Transfer Function for Gain-of-20 option

The output voltage can be calculated from:

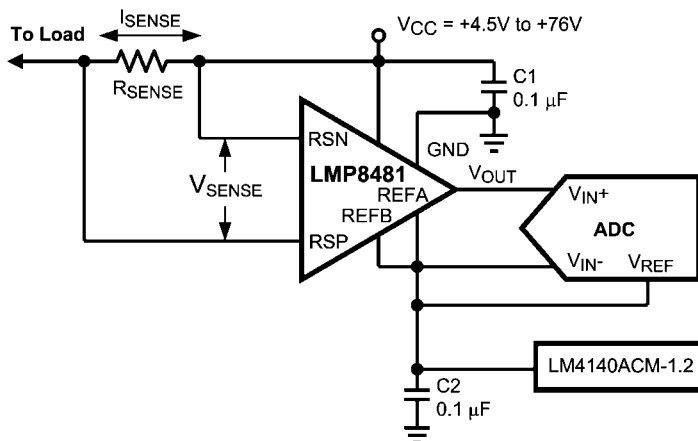
$$V_{OUT} = (V_{RSP} - V_{RSN}) * A_v$$

It should be noted that the minimum “zero” reading will be limited by the lower output swing and input offset.

The LMP8480 is functionally identical to the LMP8481, but with the V<sub>REFA</sub> and V<sub>REFB</sub> nodes grounded internally. The LMP8481 can replace the LMP8480 if both the V<sub>REF</sub> inputs (pins 6 & 7) are grounded.

**BI-DIRECTIONAL OPERATION (LMP8481 ONLY)**

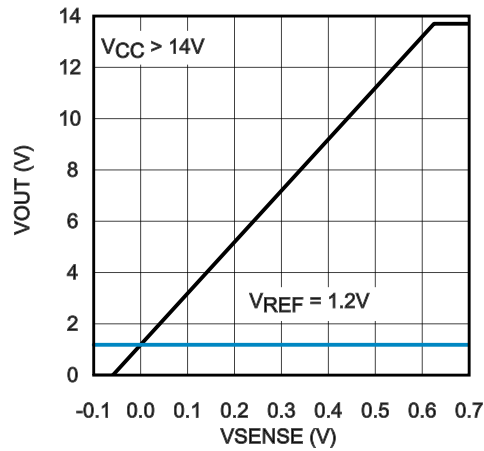
Bi-directional operation is required where the measured load current can be positive or negative. Because V<sub>SENSE</sub> can be positive or negative, and the output cannot swing negative, the “zero” output level must be level-shifted above ground to a known zero reference point. The LMP8481 allows for the setting this reference point.



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FIGURE 5. Bi-Directional current sensing using LMP8481

The V<sub>REFA</sub> and V<sub>REFB</sub> pins set the zero reference point. The output “zero” reference point is set by applying a voltage to the REFA and/or REF pin. See the [BI-DIRECTIONAL OPERATION \(LMP8481 ONLY\)](#) section below. [REFA AND REF pin \(LMP8481 Only\)](#) below shows the output transfer function with a 1.2V reference applied to the Gain-of-20 option



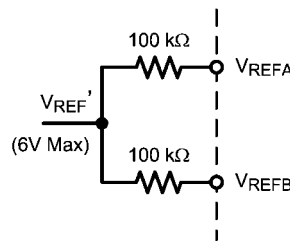
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FIGURE 6. Bi-Directional Transfer Function using 1.2V Reference Voltage

**REFA AND REFB PINS (LMP8481 Only)**

The voltage applied to the  $V_{REFA}$  and  $V_{REFB}$  pins controls the output zero reference level.

The reference inputs consist of a pair of divider resistors with equal values to a common summing point,  $V_{REF}'$ , as shown in [Figure 11](#) below.



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FIGURE 7.  $V_{REF}$  Input Resistor Network

$V_{REF}'$  is the voltage at the resistor tap point that will be directly applied to the output as an offset.

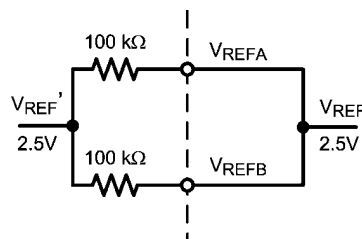
$$V_{OUT} = ((V_{RSP} - V_{RSN}) * Av) + V_{REF}'$$

Where:

$$V_{REF}' = V_{REFA} = V_{REFB} \text{ (Equal Inputs)}$$

OR

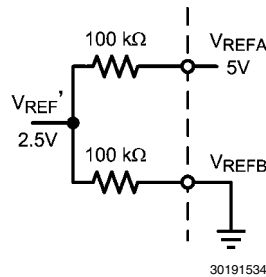
$$V_{REF}' = (V_{REFA} + V_{REFB}) / 2 \text{ (Separate inputs)}$$



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FIGURE 8. Applying 1:1 Direct Reference Voltage

For mid-range operation  $V_{REFB}$  should be tied to ground and  $V_{REFA}$  can be tied to VS or an external A/D reference voltage. The output will be set to one-half the reference voltage. For example, a 5V reference would result in a 2.5V output “zero” reference.



**FIGURE 9. Applying A Divided Reference Voltage.**

$$V_{REF'} = (V_{REFA} - V_{REFB}) / 2$$

When the reference pins are biased at different voltages, the output will be referenced to the average of the two applied voltages. The reference pins should always be driven from clean, stable sources, such as A/D reference lines or clean supply lines. Any noise or drifts on the reference inputs are directly reflected in the output. Care should be taken if the power supply is used as the reference source so as to not introduce supply noise, drift or sags into the measurement.

It is possible to set different resistor divider ratios by adding external resistors in series with the internal 100K resistors, though the temperature coefficient (tempco) of the external resistors may not tightly track the internal resistors and there will be slight errors over temperature.

### REFERENCE INPUT VOLTAGE LIMITS

The maximum voltage on either reference input pin is limited to VCC or 12V, whichever is less.

The average voltage on the two  $V_{REF}$  pins, and thus the actual output reference voltage level, is limited to a maximum of 1.5V below VCC, or 6V, whichever is less. Beware that supply voltages of less than 7.5V will have a diminishing  $V_{REF}$  maximum.

Both  $V_{REFA}$  and  $V_{REFB}$  may both be grounded to provide a ground referenced output (thus functionally duplicating the LMP8480). It should be noted that there can be a dynamic error in the  $V_{REF}$  to output level matching of up to 100 $\mu$ V/V. Normally this is not an issue for fixed references, but if the reference voltage is dynamically adjusted during operation, this error needs to be taken into account during calibration routines. This error will vary in both amplitude and polarity part-to-part, but the slope will generally be linear.

### SELECTION OF THE SENSE RESISTOR

The accuracy of the current measurement depends heavily on the accuracy of the shunt resistor  $R_{SENSE}$ . Its value depends on the application and is a compromise between small-signal accuracy, maximum permissible voltage drop and allowable power dissipation in the current measurement circuit.

The use of a “4-terminal” or “Kelvin” sense resistor is highly recommended. See the [ERROR SOURCES AND LAYOUT CONSIDERATIONS](#) below.

For best results, the value of the resistor is calculated from the maximum expected load current  $I_{LMAX}$  and the expected maximum output swing  $V_{OUTMAX}$ , plus a few percent of headroom. See the [MAXIMUM OUTPUT VOLTAGE](#) section for details about the maximum output voltage limits.

High values of  $R_{SENSE}$  provide better accuracy at lower currents by minimizing the effects of amplifier offset. Low values of  $R_{SENSE}$  minimize load voltage loss, but at the expense of accuracy at low currents. A compromise between low current accuracy and load circuit losses must generally be made.

The maximum  $V_{SENSE}$  voltage that must be generated across the  $R_{SENSE}$  resistor will be:

$$V_{SENSE} = V_{OUTMAX} / A_V$$

Note: The maximum  $V_{SENSE}$  voltage should be no more than 667mV.

From this maximum  $V_{SENSE}$  voltage, the  $R_{SENSE}$  value can be calculated from:

$$R_{SENSE} = V_{SENSE} / I_{LMAX}$$

Care must be taken to not exceed the maximum power dissipation of the resistor. The maximum sense resistor power dissipation will be:

$$P_{R_{SENSE}} = V_{SENSE} * I_{LMAX}$$

It is recommended that a 2-3x minimum safety margin be used in selecting the power rating of the resistor.

### USING PCB TRACES AS SENSE RESISTORS

While it may be tempting to use a known length of PCB trace resistance as a sense resistor, it is not recommended.

The tempco of copper is typically 3300-4000ppm/ $^{\circ}$ K, which can vary over PCB process variations and require measurement correction (possibly requiring ambient temperature measurements).

A typical surface mount sense resistor tempco is in the 50ppm to 500ppm/ $^{\circ}$ C range offering more measurement consistency and accuracy over the copper trace. Special low tempco resistors are available in the 0.1 to 50ppm range, but at a higher cost.

### INPUT COMMON MODE AND DIFFERENTIAL VOLTAGE RANGE

The input common mode range, where “common mode range” is defined as the voltage from ground to the voltage on  $R_{SP}$  input, should be in the range of +4.0V to +76V. Operation below 4.0V on either input pin will introduce severe gain error and nonlinearities. The maximum differential voltage (defined as the voltage difference between  $R_{SP}$  and  $R_{SN}$ ) should be 667mV or less. The theoretical maximum input is 700mV ( $14V / 20$ ).

Taking the inputs below 4V will not damage the device, but the output conditions during this time are not predictable and are not guaranteed.

If the load voltage ( $V_{cm}$ ) is expected to fall below 4V as part of normal operation, preparations must be made for invalid output levels during this time.

### LOW SIDE CURRENT SENSING

The LMP8480 and LMP8481 are **not** recommended for low-side current sensing at ground level. The voltage on either input pin must be a minimum of 4.0V above the ground pin for proper operation.

### INPUT SERIES RESISTANCE

Because the input stage uses precision resistors to convert the voltage on the input pin to a current, any resistance added in series with the input pins will change the gain. If a resistance is added in series with an input, the gain of that input will not track that of the other input, causing a constant gain error.

It is not recommended to use external resistances to alter the gain, as external resistors will not have the same thermal matching as the internal thin film resistors.

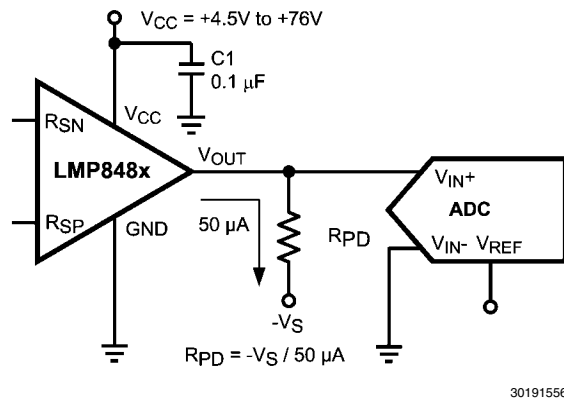
If resistors are purposely added for filtering, resistance should be added equally to both inputs and the user should be aware that the gain will change slightly. See end of the [THEORY OF OPERATION](#) section for the internal resistor values.

### MINIMUM OUTPUT VOLTAGE

The amplifier output cannot swing to exactly zero volts. There will always be a minimum output voltage set by the output transistor saturation and input offset errors. This will create a minimum output swing around the zero current reading due to the output saturation. The user should be aware of this when designing any servo loops or data acquisition systems that may assume  $0V = 0A$ . If a true zero is required, the LMP8481 should be used with a  $V_{REF}$  set slightly above ground ( $>50mV$ ). See the [SWINGING OUTPUT BELOW GROUND](#) section below for a possible solution to this issue.

### SWINGING OUTPUT BELOW GROUND

If a negative supply is available, a pull-down resistor can be added from the output to the negative voltage to allow the output to swing a few millivolts below ground. This will now allow the ADC to resolve true zero and recover codes that would normally be lost to the negative output saturation limit.



**FIGURE 10. Output “Pull-Down” Resistor Example**

A minimum of  $50\mu A$  should be sourced (“pulled”) from the output to a negative voltage. The pulldown resistor can be calculated from:

$$R_{PD} = -V_S / 50\mu A$$

For example, if a -5V supply is available, a pull-down resistor of  $5V / 50\mu A = 100K$  should be used. This will allow the output to swing to about 10mV below ground.

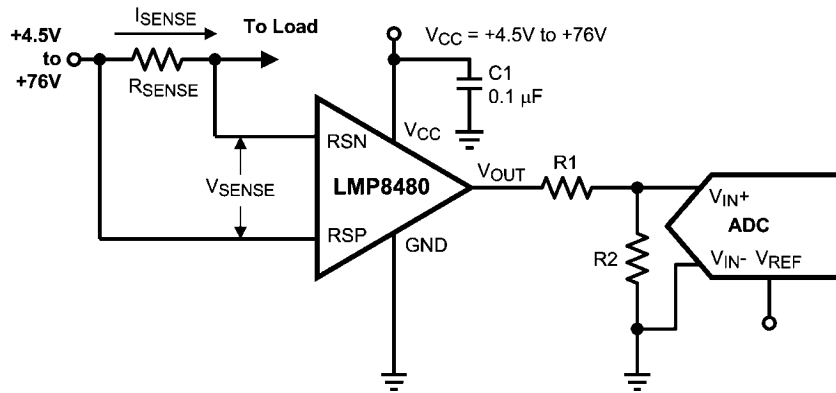
This technique may also reduce the maximum positive swing voltage. Do not forget to include the parallel loading effects of the pulldown any output load. It is recommended not to exceed -100mV on the output. Source currents greater than  $100\mu A$  should be avoided to prevent self-heating at high supply voltages. Pulldown resistor values should not be so low as to heavily load the output during positive output excursions. This mode of operation is not directly specified and is not guaranteed.

### MAXIMUM OUTPUT VOLTAGE

The LMP8481 has an internal precision 14V low dropout regulator which limits the maximum amplifier output swing to about 250mV below  $V_{CC}$  or 13.7V (whichever is less). This effectively clamps the maximum output to slightly less than 13.7V even with a  $V_{CC}$  greater than 14V.

Care should be taken if the output is driving an A/D input with a maximum A/D maximum input voltage lower than the amplifier supply voltage, as the output can swing higher than the planned load maximum due to input transients or shorts on the load and overload or possibly damage the A/D input.

A resistive attenuator, as shown in [Figure 11](#) below, can be used to match the maximum swing to the input range of the A/D.

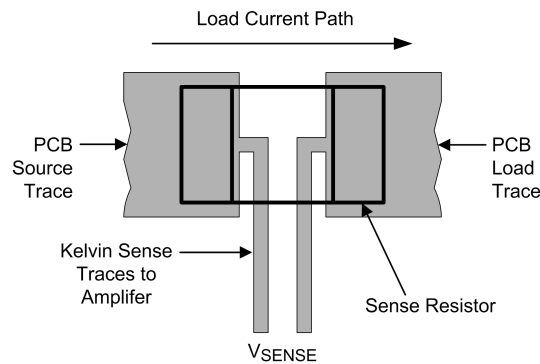


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**FIGURE 11. Typical Application with Resistive Divider**

### ERROR SOURCES AND LAYOUT CONSIDERATIONS

The traces leading to and from the sense resistor can be significant error sources. With small value sense resistors (<100m), any trace resistance shared with the load current can cause significant errors.



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**FIGURE 12. "Kelvin" or "4-wire" Connection to the Sense Resistor**

The amplifier inputs should be directly connected to the sense resistor pads using "Kelvin" or "4-wire" connection techniques. The traces should be one continuous piece of copper from the sense resistor pad to the amplifier input pin pad, and ideally on the same copper layer with minimal vias or connectors. This can be important around the sense resistor if it is generating any significant heat gradients.

To minimize noise pickup and thermal errors, the input traces should be treated as a differential signal pair and routed tightly together with a direct path to the input pins. The input traces should be run away from noise sources, such as digital lines, switching supplies or motor drive lines. Remember that these traces can contain high voltage, and should have the appropriate trace routing clearances.

Since the sense traces only carry the amplifier bias current (about 7μA at room temp), the connecting input traces can be thinner, signal level traces. Excessive Resistance in the trace should also be avoided.

The paths of the traces should be identical, including connectors and vias, so that these errors will be equal and cancel.

The sense resistor will heat up as the load increases. As the resistor heats up, the resistance generally goes up, which will cause a change in the readings. The sense resistor should have as much heatsinking as possible to remove this heat through the use of heatsinks or large copper areas coupled to the resistor pads. A reading drifting over time after turn-on can usually be traced back to sense resistor heating.

**POWER SUPPLY DECOUPLING**

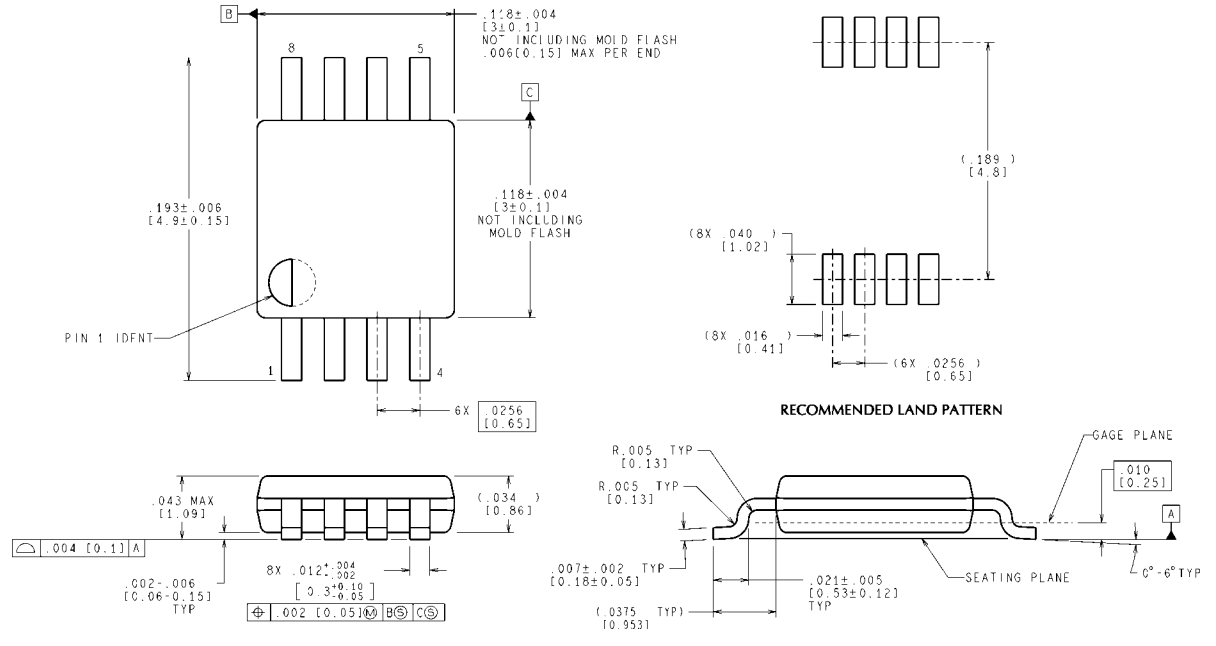
In order to decouple the LMP8480/81 from AC noise on the power supply, it is recommended to use a 0.1  $\mu\text{F}$  bypass capacitor between the  $V_{\text{CC}}$  and GND pins. This capacitor should be placed as close as possible to the supply pins. In some cases an additional 10  $\mu\text{F}$  bypass capacitor may further reduce the supply noise.

Do not forget that these bypass capacitors must be rated for the full supply and/or load source voltage! It is recommended that the working voltage of the capacitor (WVDC) should be at least two times the maximum expected circuit voltage.

**LLP DIE ATTACH PAD**

The bottom thermal pad of the LLP package should be tied to the same ground as the ground pin. Be aware that noise on this pad can couple into the bottom of the die, so the ground should be as clean as possible.

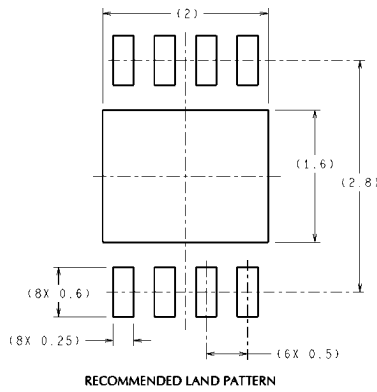
# Physical Dimensions inches (millimeters) unless otherwise noted



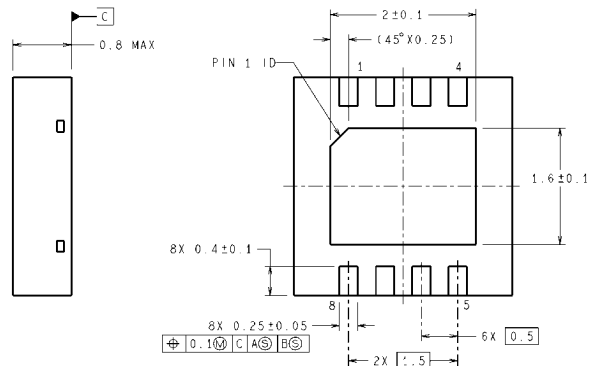
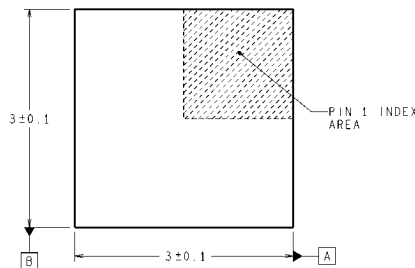
CONTROLLING DIMENSION IS INCH  
VALUES IN [ ] ARE MILLIMETERS

MUA08A (Rev F)

## MSOP-8 NS Package Number MUA08A



DIMENSIONS ARE IN MILLIMETERS  
DIMENSIONS IN ( ) FOR REFERENCE ONLY



SDA08A (Rev A)

## LLP-8 NS Package Number SDA08A

**Warning:** LLP-8 thermal pad shall be tied to GND

## Notes

# Notes

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