February 9, 2012

LMP8278Q

High Common Mode, 14 x Gain, Precision Current Sensing Amplifier

General Description

The LMP8278 is a fixed 14x gain precision current sense amplifier. The part amplifies and filters small differential signals in the presence of high common mode voltages. The part operates from a single 5V supply voltage. With an input common mode voltage range from -2V to +28V the gain is very precise (±0.5%). The part can handle common mode voltages in the range -2V to +40V with relaxed specifications. The LMP8278 is a member of the Linear Monolithic Precision (LMP®) family and is ideal for unidirectional current sensing applications. The parameter values that are shown in the Electrical Characteristics table are 100% tested and all bold values are also 100% tested over temperature, unless otherwise noted.

The part has a precise gain of 14x which is adequate in most targeted applications to drive an ADC to its full scale value. The fixed gain is achieved in two separate stages, a preamplifier with a gain of 7x and an output stage buffer amplifier with a gain of 2x. The connection between the two stages of the signal path is brought out on two pins to enable the possibility to create an additional filter network around the output buffer amplifier. These pins can also be used for alternative configurations with different gain as described in the applications section.

The LMP8278Q incorporates enhanced manufacturing and support processes for the automotive market, including defect detection methodologies. Reliability qualification is compliant with the requirements and temperature grades defined in the AEC Q100 standard.

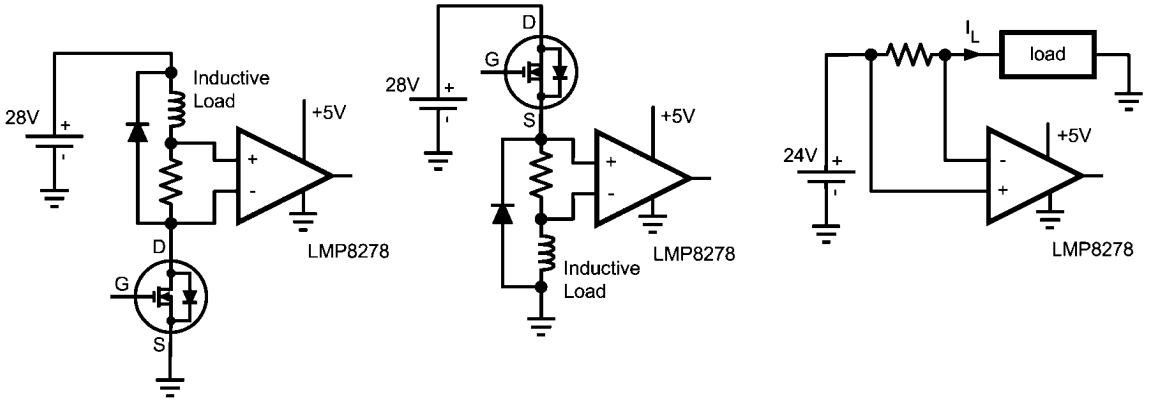
Features

- TCVos ±15µV/°C max
- CMRR 80 dB min
- Input offset voltage ±2 mV max
- CMVR –2V to 40V
- Operating ambient temperature range –40°C to 125°C
- Single supply operation
- Min / Max limits 100% tested unless otherwise noted
- LMP8278Q available in Automotive AEC-Q100 Grade 1 qualified version

Applications

- High side and low side driver configuration current sensing
- Automotive fuel injection control
- Transmission control
- Power steering
- Battery management systems

Typical Applications

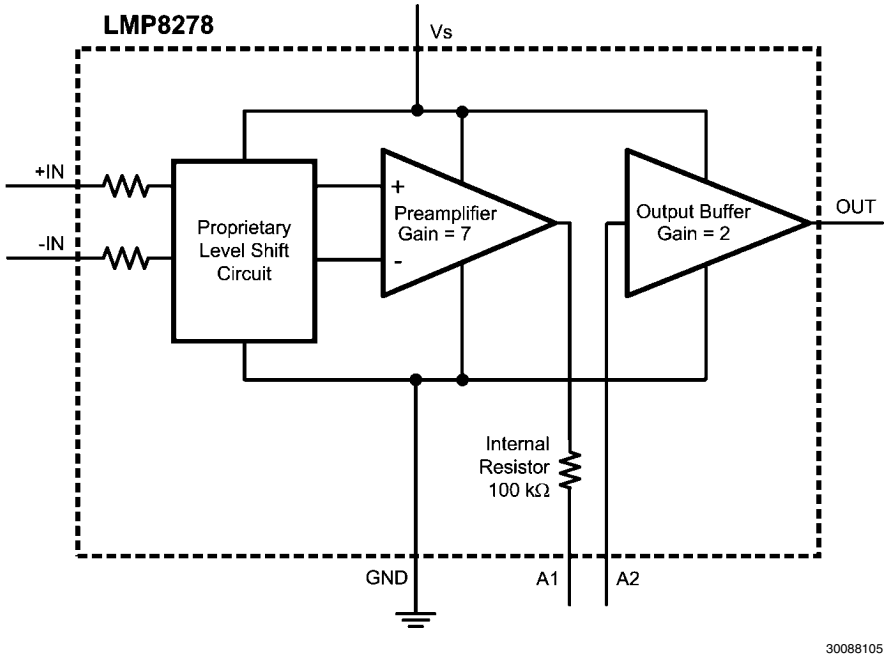


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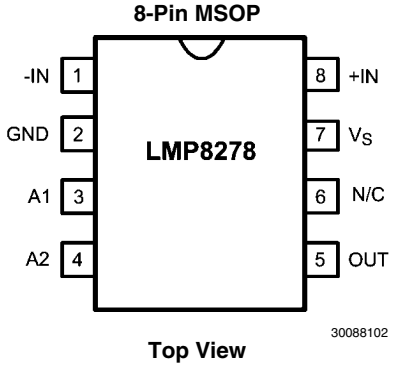
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Block Diagram



Connection Diagram



Top View

Pin Descriptions

	Pin	Name	Description
Power Supply	2	GND	Power Ground
	7	V_S	Positive Supply Voltage
Inputs	1	−IN	Negative Input
	8	+IN	Positive Input
Filter Network	3	A1	Preamplifier output
	4	A2	Input from the external filter network and / or A1
Output	5	OUT	Single ended output
NC	6	N/C	No Connect (floating)

Ordering Information

Package	Part Number	Package Marking	Transport Media	NSC Drawing
8–Pin MSOP	LMP8278QMM	AB7A	95 Units/Rail	MUA08A
	LMP8278QMMX		3.5K Units Tape and Reel	

Automotive Grade (Q) product incorporates enhanced manufacturing and support processes for the automotive market, including defect detection methodologies. Reliability qualification is compliant with the requirements and temperature grades defined in the AEC Q100 standard. Automotive Grade products are identified with the letter Q. Fully compliant PPAP documentation is available. For more information go to http://www.national.com/automotive.

Absolute Maximum Ratings (Note 1)

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

ESD Tolerance (Note 4)	
Human Body	
For input pins only	±8000V
For all other pins	±2000V
Machine Model	200V
Charge Device Model	1000V
Supply Voltage (V_S - GND)	6V
Continuous Input Voltage (–IN and +IN) (Note 6)	–12V to 50V
Max Voltage at A1, A2 and OUT	V_S +0.3V
Min Voltage at A1, A2 and OUT	GND -0.3V
Storage Temperature Range	–65°C to 150°C
Junction Temperature (Note 3)	150°C

For soldering specs see:
www.national.com/ms/MS/MS-SOLDERING.pdf

Operating Ratings (Note 1)

Supply Voltage (V_S – GND)	4.5V to 5.5V
Temperature Range (Note 3)	–40°C to +125°C
Package Thermal Resistance (Note 3)	
8-Pin MSOP (θ_{JA})	230°C/W

5.0V Electrical Characteristics (Note 2)

Unless otherwise specified, all limits guaranteed at T_A = 25°C, V_S = 5.0V, GND = 0V, –2V ≤ V_{CM} ≤ 28V, and R_L = ∞, 10nF between V_S and GND. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 7)	Typ (Note 5)	Max (Note 7)	Units
Overall Performance (From –IN (pin 1) and +IN (pin 8) to OUT (pin 5) with pins A1 (pin 3) and A2 (pin 4) connected)						
I_S	Supply Current		**0.3**	0.4	**0.55**	mA
A_V	Total Gain	–2V < V_{CM} < 28V	13.93	14	14.07	V/V
		–2V < V_{CM} < 40V	13.86	14	14.14	
	Gain Drift	–40°C ≤ T_A ≤ 125°C		±2	**±25**	ppm/°C
SR	Slew Rate	V_{IN} = ±0.2V		0.7		V/µs
BW	Bandwidth			90		kHz
V_{OS}	Input Offset Voltage	V_{CM} = V_S / 2		±0.25	±2	mV
TCV_{OS}	Input Offset Voltage Drift (Note 8)	–40°C ≤ T_A ≤ 125°C		±2.5	**±15**	µV/°C
e_n	Input Referred Voltage Noise	0.1 Hz – 10 Hz, 6–Sigma		11		μV_{PP}
		Spectral Density, 1 kHz		285		nV/√Hz
PSRR	Power Supply Rejection Ratio	DC,4.5V ≤ V_S ≤ 5.5V, V_{CM} = V_S/2	**70**	80		dB
Preamplifier (From input pins –IN (pin 1) and +IN (pin 8) to A1 (pin 3))						
R_{CM}	Input Impedance Common Mode	–2V ≤ V_{CM} ≤ 40	**100**	125		kΩ
R_{DM}	Input Impedance Differential Mode (Note 13)	–2V ≤ V_{CM} ≤ 40	60	85		kΩ
V_{OS}	Input Offset Voltage	V_{CM} = V_S / 2		±0.25	±2	mV
TCV_{OS}	Input Offset Voltage Drift (Note 8)	–40°C ≤ T_A ≤ 125°C		±2.5	**±15**	µV/°C
DC CMRR	DC Common Mode Rejection Ratio	–2V ≤ V_{CM} ≤ 40V	**80**	90		dB
AC CMRR	AC Common Mode Rejection Ratio	f = 1 kHz		90		dB
		f = 10 kHz		85		
CMVR	Input Common Mode Voltage Range	for 80 dB CMRR	**–2**		**40**	V
$A1_V$	Gain		6.93	7.0	7.07	V/V
R_{F-INT}	Output Impedance Filter Resistor		**97**	100	**103**	kΩ
TCR_{F-INT}	Output Impedance Filter Resistor Drift			20	**±100**	ppm/°C
A1 V_{OUT}	Preamplifier Output Voltage Swing	V_{OL}, R_L = ∞		4	**10**	mV
		V_{OH}, R_L = ∞	**4.80**	4.95		V
Output Buffer (From A2 (pin 4) to OUT (pin 5))						
V_{OS}	Input Offset Voltage	0V ≤ V_{CM} ≤ V_S–1		±0.25	**±2**	mV
$A2_V$	Gain		1.98	2	2.02	V/V

Symbol	Parameter	Conditions		Min (*Note 7*)	Typ (*Note 5*)	Max (*Note 7*)	Units
I_B	Input Bias Current of Output Buffer (*Note 9*, *Note 13*)				±20		pA
						±20	nA
A2 V_{OUT}	Output Buffer Output Voltage Swing (*Note 10*, *Note 11*)	V_{OL}	R_L = 100 kΩ		7	**20**	mV
		V_{OH}		**4.80**	4.99		V
A2 V_{OUT}	Output Buffer Output Voltage Swing (*Note 10*, *Note 11*)	V_{OL}	R_L = 10 kΩ		15	30	mV
		V_{OH}		4.75	4.95		V
I_{SC}	Output Short-Circuit Current (*Note 9*, *Note 12*)	Sourcing, $V_{IN} = V_S$, V_{OUT} = GND		-10			mA
		Sinking, V_{IN} = GND, $V_{OUT} = V_S$		10			

Note 1: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur, including inoperability and degradation of the device reliability and/or performance. Functional operation of the device and/or non-degradation at the Absolute Maximum Ratings or other conditions beyond those indicated in the Recommended Operating Conditions is not implied. The Recommended Operating Conditions indicate conditions at which the device is functional and the device should not be beyond such conditions. All voltages are measured with respect to the ground pin, unless otherwise specified.

Note 2: The Electrical Characteristics table lists guaranteed specifications under the listed Recommended Operating Conditions except as otherwise modified or specified by the Electrical Characteristics Conditions and/or Notes. Typical specifications are estimations only and are not guaranteed.

Note 3: The maximum power dissipation must be derated at elevated temperatures and is dictated by $T_{J(MAX)}$, θ_{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 4: Human Body Model per MIL-STD-883, Method 3015.7. Machine Model, per JESD22-A115-A. Field-Induced Charge-Device Model, per JESD22-C101-C.

Note 5: Typical values represent the most likely parameter norms at T_A = +25°C and at the Recommended Operation Conditions at the time of product characterization and are not guaranteed.

Note 6: For the MSOP package, the pitch of the solder pads is too narrow for reliable use at higher voltages (V_{CM} >25V). Therefore, it is strongly advised to add a conformal coating on the PCB assembled with the LMP8278 / LMP8278Q.

Note 7: Datasheet min/max specification limits are guaranteed by test, unless otherwise noted.

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

Note 9: Positive current corresponds to current flowing into the device.

Note 10: For this test input is driven from A1 stage.

Note 11: For V_{OL}, R_L is connected to V_S and for V_{OH}, R_L is connected to GND.

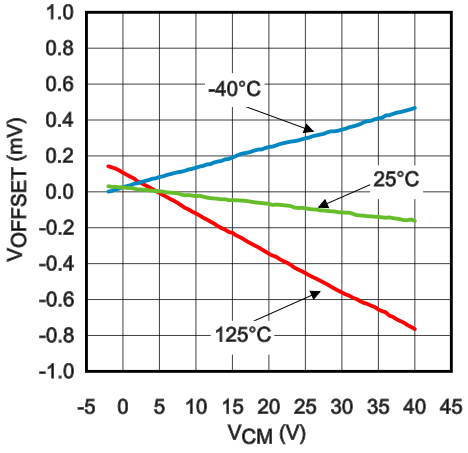
Note 12: Short-Circuit test is a momentary test. Continuous short circuit operation at elevated ambient temperature can result in exceeding the maximum allowed junction temperature of 150°C.

Note 13: Specification is guaranteed by design and is not tested in production.

Typical Performance Characteristics

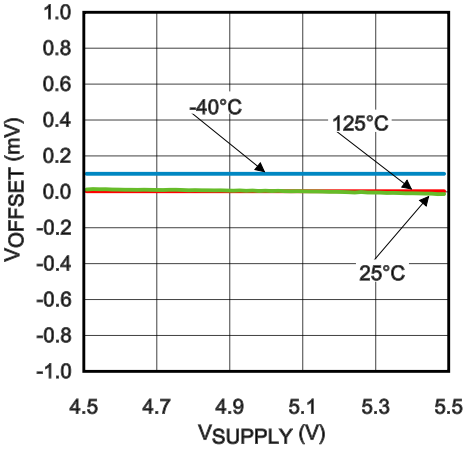
Unless otherwise specified, measurements taken at T_A = 25°C, V_S = 5V, GND = 0V, −2V ≤ V_{CM} ≤ 28V, and R_L = ∞, 10nF between V_S and GND.

V_{OS} vs. V_{CM}



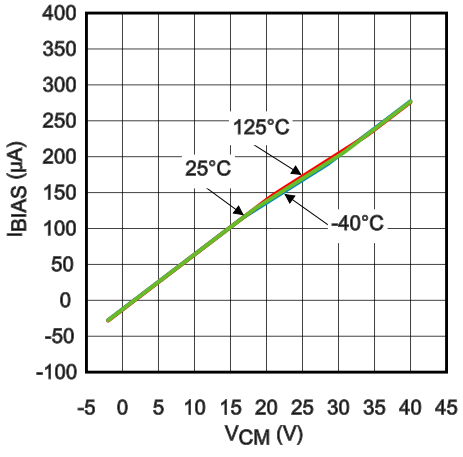
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V_{OS} vs. V_S



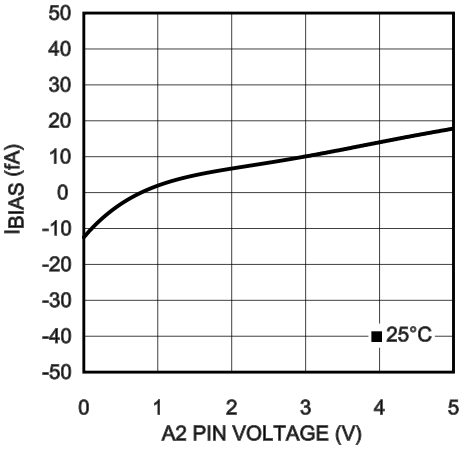
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A1 Input Bias Current vs. V_{CM}



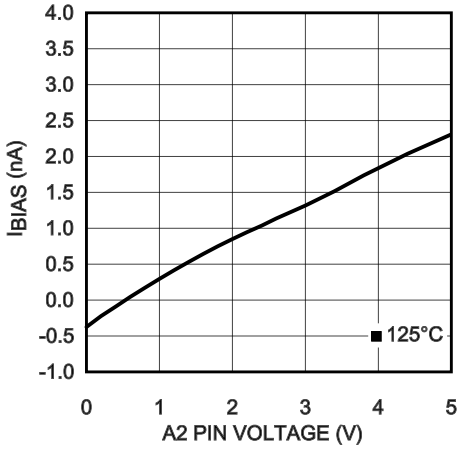
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A2 Input Bias Current vs. V_{CM}, at 25°C



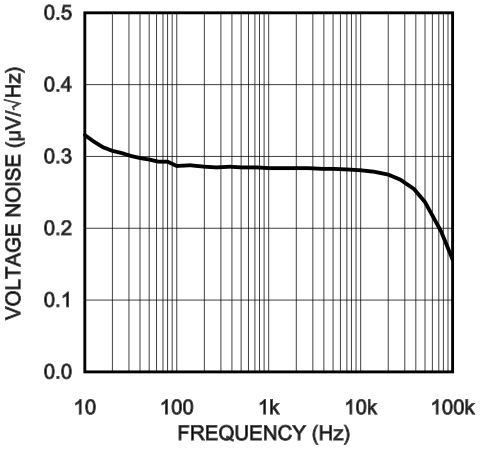
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A2 Input Bias Current vs. V_{CM}, at 125°C



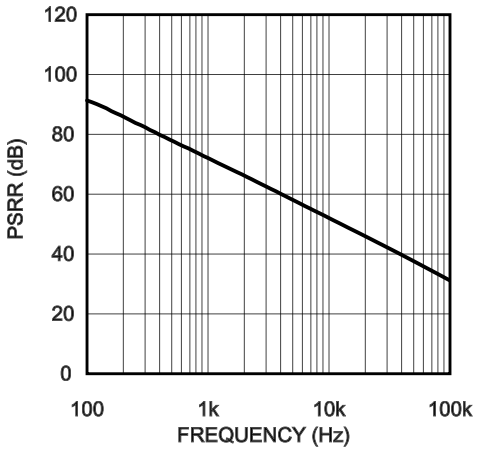
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Input Referred Voltage Noise vs. Frequency



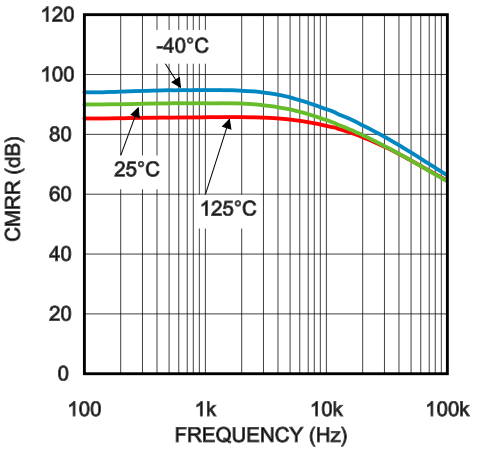
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PSRR vs. Frequency



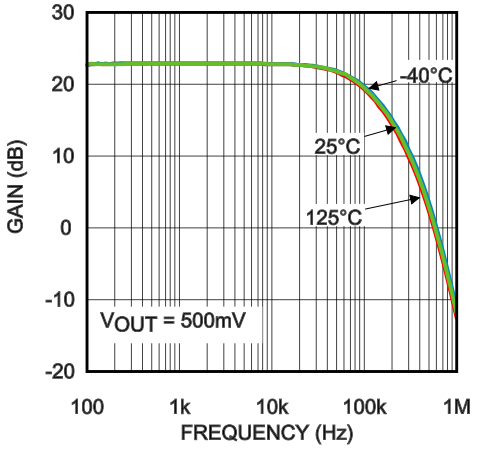
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CMRR vs. Frequency



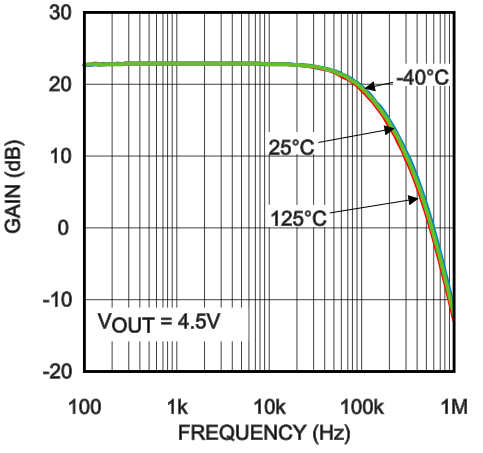
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Gain vs. Frequency, V_{out}=500mV



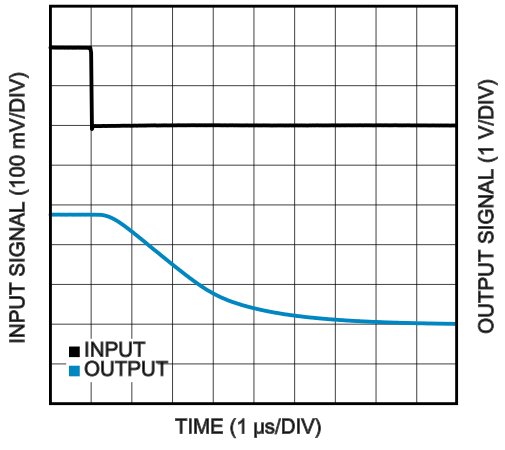
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Gain vs. Frequency, V_{out}=4.5V



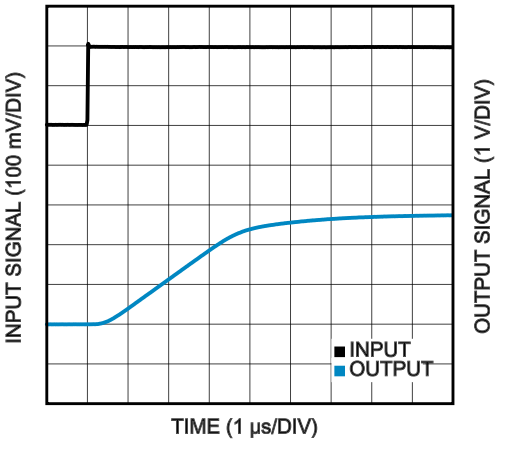
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Settling Time (Falling Edge)



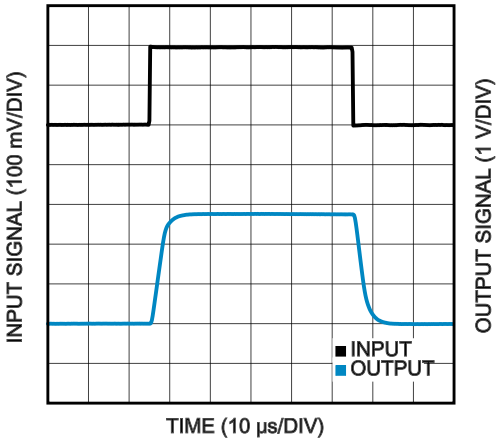
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Settling Time (Rising Edge)



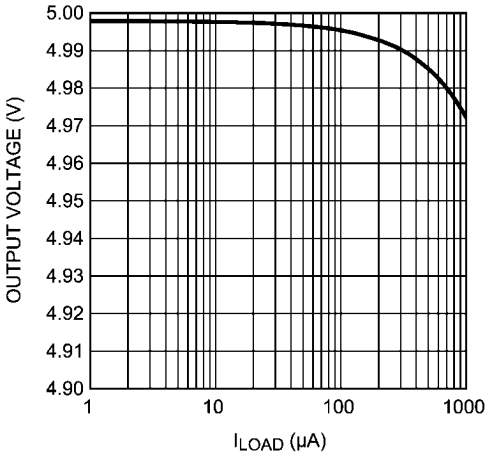
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Step Response



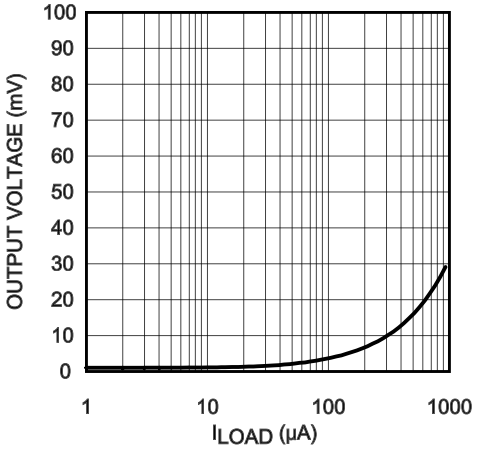
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Positive Swing vs. I_{LOAD}



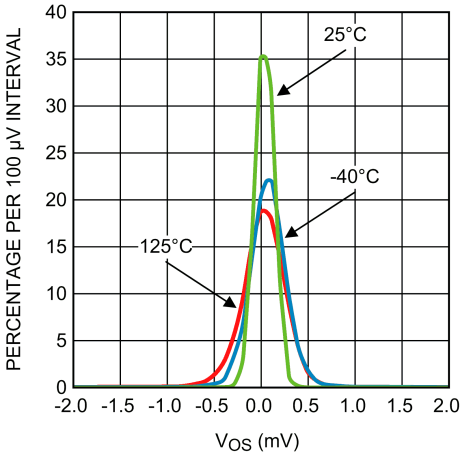
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Negative Swing vs. I_{LOAD}



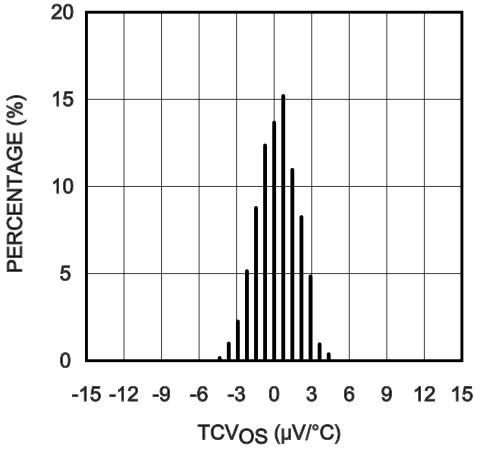
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V_{OS} Distribution



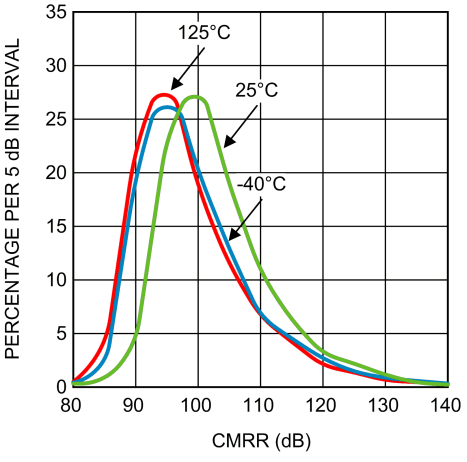
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TCV_{OS} Distribution



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CMRR Distribution



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Application Information

GENERAL

The LMP8278 is a fixed gain differential voltage precision amplifier with a gain of 14x and a -2V to +40V input common mode voltage range when operating from a single 5V supply. The LMP8278 is a member of the LMP family and is ideal for unidirectional current sensing applications. Because of its proprietary level-shift input stage the LMP8278 achieves very low offset, very low thermal offset drift, and very high CMRR. The LMP8278 amplifies and filters small differential signals in the presence of high common mode voltages.

The LMP8278 uses level shift resistors at the inputs. Because of these resistors, the LMP8278 can easily withstand very large differential input voltages that may exist in fault conditions where some other less protected current sense amplifiers might sustain permanent damage.

The LMP8278 is available in an 8–Pin MSOP package. For the MSOP package, the pitch of the solder pads is too narrow for reliable use at higher voltages (V_{CM} > 25V). Therefore, it is strongly advised to add a conformal coating on the PCB assembled with the LMP8278 in MSOP package.

PERFORMANCE GUARANTIES

To guaranty the high performance of the LMP8278, minimum and maximum values shown in the Electrical Characteristics table of this datasheet are 100% tested and all bold limits are also 100% tested over temperature, unless otherwise noted.

THEORY OF OPERATION

The schematic shown in *Figure 1* gives a schematic representation of the internal operation of the LMP8278.

The signal on the input pins is typically a small differential voltage across a current sensing shunt resistor. The input signal may appear at a high common mode voltage. The input signals are accessed through two input resistors. The proprietary level shift circuit brings the common mode voltage behind the input resistors within the supply rails. Subsequently, the signal is gained up by a factor of 7 and brought out on the A1 pin through a trimmed 100 kΩ resistor. In the application, additional gain adjustment or filtering components can be added between the A1 and A2 pins as will be explained in subsequent sections. The signal on the A2 pin is further amplified by a factor of 2 and brought out on the OUT pin.

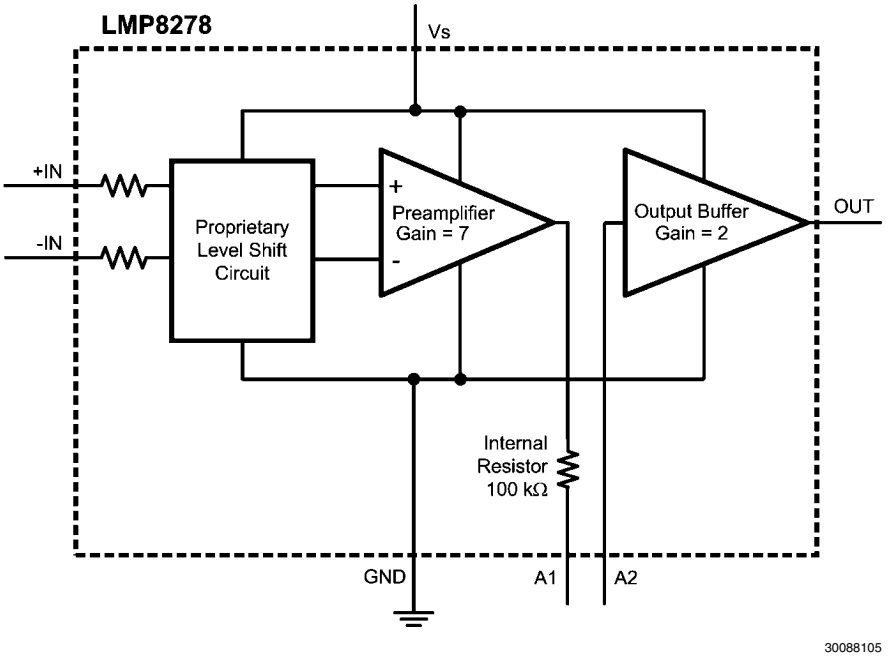


FIGURE 1. Theory of Operation

ADDITIONAL SECOND ORDER LOW PASS FILTER

The bandwidth of the output buffer can be reduced by adding a capacitor on the A1 pin to create a first order low pass filter with a time constant determined by the 100 kΩ internal resistor and the external filter capacitor.

It is also possible to create an additional second order Sallen-Key low pass filter, as illustrated in *Figure 2*, by adding external components R_2, C_1 and C_2. Together with the internal 100 kΩ resistor R_1, this circuit creates a second order low-pass filter characteristic.

When the corner frequency of the additional filter is much lower than 90 kHz, the transfer function of the described amplifier can be written as:

$$H(s) = \frac{K_1 * K_2 \frac{1}{R_1R_2C_1C_2}}{s^2 + s * \left[\frac{1}{R_1C_2} + \frac{1}{R_2C_2} + \frac{(1 - K_2)}{R_2C_1}\right] + \frac{1}{R_1R_2C_1C_2}}$$

Where K_1 equals the gain of the preamplifier and K_2 that of the buffer amplifier.

The above equation can be written in the normalized frequency response for a 2nd order low pass filter:

$$G(j\omega) = K_1 * \frac{K_2}{\frac{(j\omega)^2}{\omega_o^2} + \frac{j\omega}{Q\omega_o} + 1}$$

The cutt-off frequency ω_o in rad/sec (divide by 2π to get the cut-off frequency in Hz) is given by:

$$\omega_o = \frac{1}{\sqrt{R_1R_2C_1C_2}}$$

And the quality factor of the filter is given by:

$$Q = \frac{\sqrt{R_1R_2C_1C_2}}{R_1C_1 + R_2C_1 + (1 - K_2) * R_1C_2}$$

With K_2>1x, the above equation results in:

$$Q = \frac{\sqrt{R_1R_2 \frac{C_1^2}{(K\text{-}1)}}}{R_1C_1 + R_2C_1 - \frac{(K\text{-}1)R_1C_2}{(K\text{-}1)}}$$

For any filter gain K > 1x, the design procedure can be very simple if the two capacitors are chosen in a certain ratio.

$$C_2 = \frac{C_1}{K - 1}$$

In this case, given the predetermined value of R1 = 100 kΩ (the internal resistor), the quality factor is set solely by the value of the resistor R_2.

R_2 can be calculated based on the desired value of Q as the first step of the design procedure with the following equation:

$$R_2 = \frac{R_1}{(K\text{-}1)Q^2}$$

For the gain of 2 for the LMP8278 this results in:

$$R_2 = \frac{R_1}{Q^2}$$

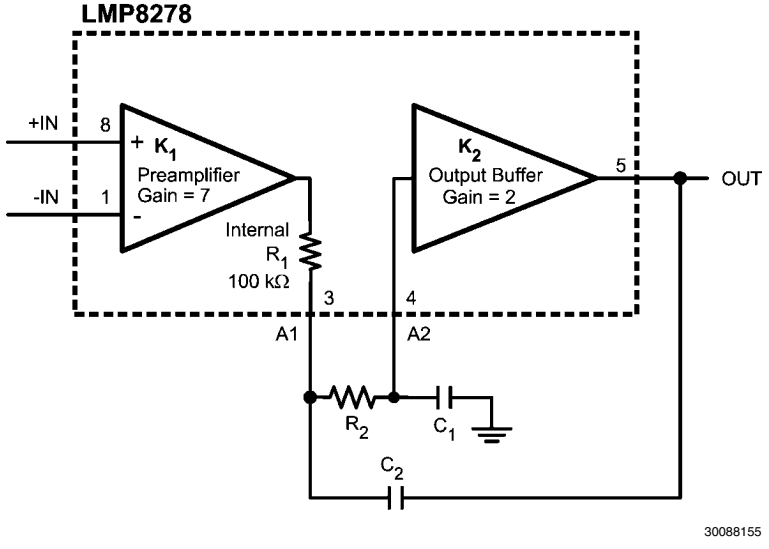


FIGURE 2. Second Order Low Pass Filter

For instance, the value of Q can be set to $0.5\sqrt{2}$ to create a Butterworth response, to $1/\sqrt{3}$ to create a Bessel response, or to 0.5 to create a critically damped response. Once the value of R_2 has been found, the second and last step of the design procedure is to calculate the required value of C to give the desired low-pass cut-off frequency using:

$$C_1 = \frac{(K-1)Q}{R_1\omega_0}$$

Which for the gain=2 will give:

$$C1 = \frac{Q}{R_1\omega_0}$$

For C_2 the value is calculated with:

$$C_2 = \frac{C_1}{K-1}$$

Or, for a gain=2, C2=C1

Note that the frequency response achieved using this procedure will only be accurate if the cut-off frequency of the second order filter is much smaller than the intrinsic 90 kHz low-pass response. In other words, choose the frequency response of the circuit such that the internal poles of the LMP8278 do not affect the external second order filter.

For a desired Q = 0.707 and a cut off frequency = 3 kHz, this will result in rounded values for R_2 = 200 kΩ, C_1:C_2 = 390 pF.

GAIN ADJUSTMENT

The gain of the LMP8278 is 14; however, this gain can be adjusted as the signal path in between the two internal amplifiers is available on the external pins.

Reduce Gain

Figure 3 shows the configuration that can be used to reduce the gain of the LMP8278.

R_r creates a resistive divider together with the internal 100 kΩ resistor such that the reduced gain G_r becomes:

$$G_r = \frac{14\ R_r}{R_r + 100\ k\Omega}$$

Given a desired value of the reduced gain G_r, using this equation the required value for R_r can be calculated with:

$$R_r = 100\ k\Omega \times \frac{G_r}{14 - G_r}$$

Increase Gain

Figure 4 shows the configuration that can be used to increase the gain of the LMP8278.

R_i creates positive feedback from the output pin to the input of the buffer amplifier. The positive feedback increases the gain. The increased gain G_i becomes:

$$G_i = \frac{14\ R_i}{R_i - 100\ k\Omega}$$

From this equation, for a desired value of the gain, the required value of R_i can be calculated with:

$$R_i = 100\ k\Omega \times \frac{G_i}{G_i - 14}$$

It should be noted from the equation for the gain G_i that for large gains R_i approaches 100 kΩ. In this case, the denominator in the equation becomes close to zero. In practice, for large gains the denominator will be determined by tolerances in the values of the external resistor R_i and the internal 100 kΩ resistor. In this case, the gain becomes very inaccurate. If the denominator becomes equal to zero, the system will even become unstable. It is recommended to limit the application of this technique to gain values of 35 or smaller.

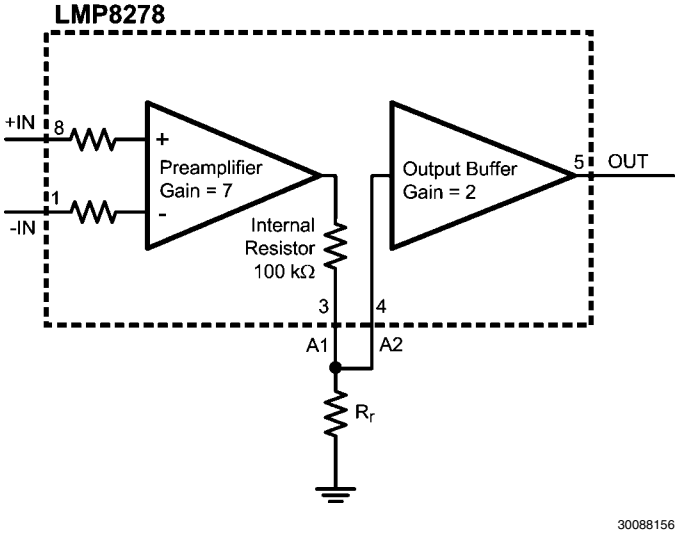


FIGURE 3. Reduce Gain

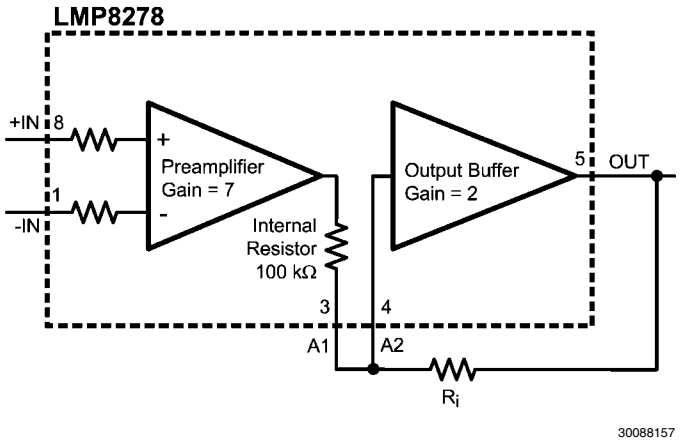


FIGURE 4. Increase Gain

POWER SUPPLY DECOUPLING

In order to decouple the LMP8278 from AC noise on the power supply, it is recommended to use a 0.1 µF bypass capacitor between the V_S and GND pins. This capacitor should be placed as close as possible to the supply pins. In some cases an additional 10 µF bypass capacitor may further reduce the supply noise.

DRIVING SWITCHED CAPACITIVE LOADS

Some ADCs load their signal source with a sample and hold capacitor. The capacitor may be discharged prior to being connected to the signal source. If the LMP8278 is driving such ADCs the sudden current that should be delivered when the sampling occurs may disturb the output signal. This effect was simulated with the circuit shown in *Figure 5* where the output is connected to a capacitor that is driven by a rail to rail square wave.

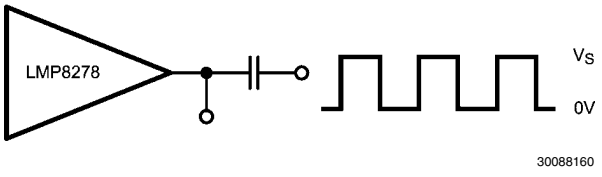


FIGURE 5. Driving Switched Capacitive Load

This circuit simulates the switched connection of a discharged capacitor to the LMP8278 output. The resulting V_{OUT} disturbance signal is shown in *Figure 6*.

The figure can be used to estimate the disturbance that will be caused when driving a switched capacitive load. To minimize the error signal introduced by the sampling that occurs on the ADC input, an additional RC filter can be placed in between the LMP8278 and the ADC as illustrated in *Figure 7*.

The external capacitor absorbs the charge that flows when the ADC sampling capacitor is connected. The external capacitor should be much larger than the sample and hold capacitor at the input of the ADC and the RC time constant of the external filter should be such that the speed of the system is not affected.

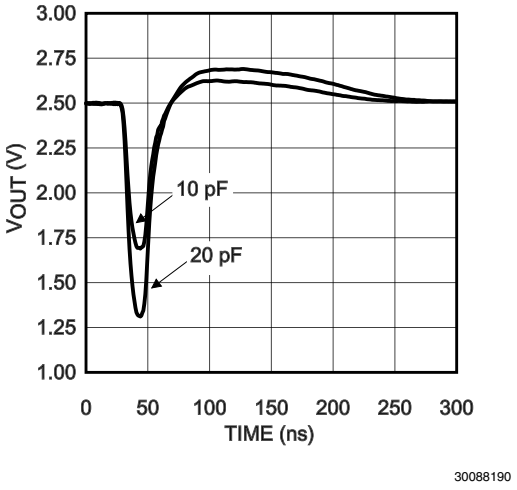


FIGURE 6. Capacitive Load Response

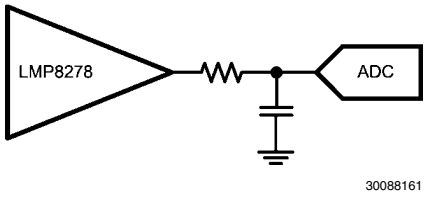


FIGURE 7. Reduce Error When Driving ADCs

LOW SIDE CURRENT SENSING APPLICATION

Figure 8 illustrates a low side current sensing application with a low side driver. The power transistor is pulse width modulated to control the average current flowing through the inductive load which is connected to a relatively high battery voltage. The current through the load is measured across a shunt resistor R_{SENSE} in series with the load. When the power transistor is on, current flows from the battery through the inductive load, the shunt resistor and the power transistor to ground. In this case, the common mode voltage on the shunt is close to ground. When the power transistor is off, current flows through the inductive load, through the shunt resistor and through the freewheeling diode. In this case the common mode voltage on the shunt is at least one diode voltage drop above the battery voltage. Therefore, in this application the common mode voltage on the shunt is varying between a large positive voltage and a relatively low voltage. Because the large common mode voltage range of the LMP8278 and because of the high AC common mode rejection ratio, the LMP8278 is very well suited for this application.

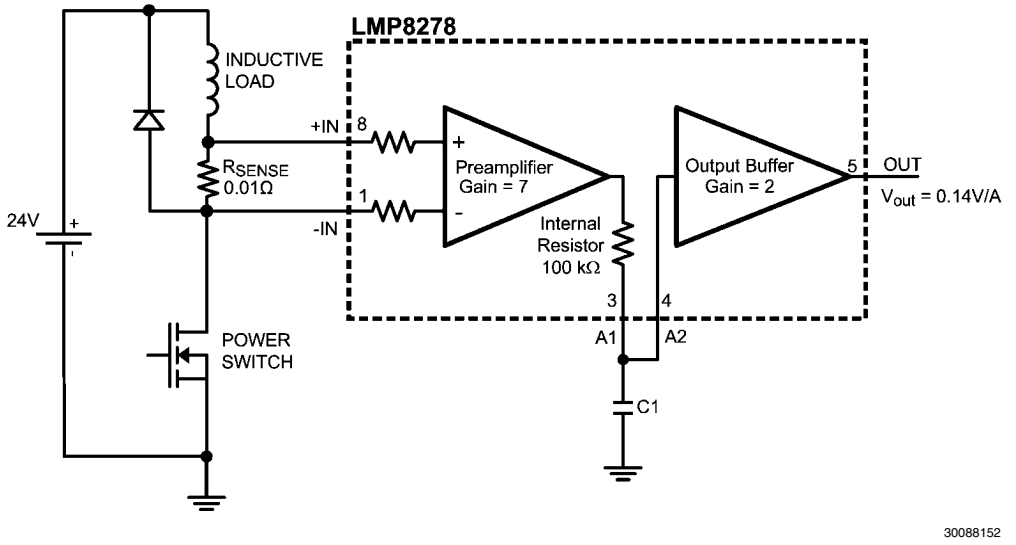


FIGURE 8. Low Side Current Sensing Application

HIGH SIDE CURRENT SENSING APPLICATION

Figure 9 illustrates the application of the LMP8278 in a high side sensing application. This application is similar to the low side sensing discussed above, except in this application the common mode voltage on the shunt drops below ground when the driver is switched off. Because the common mode voltage range of the LMP8278 extends below the negative rail, the LMP8278 is also very well suited for this application.

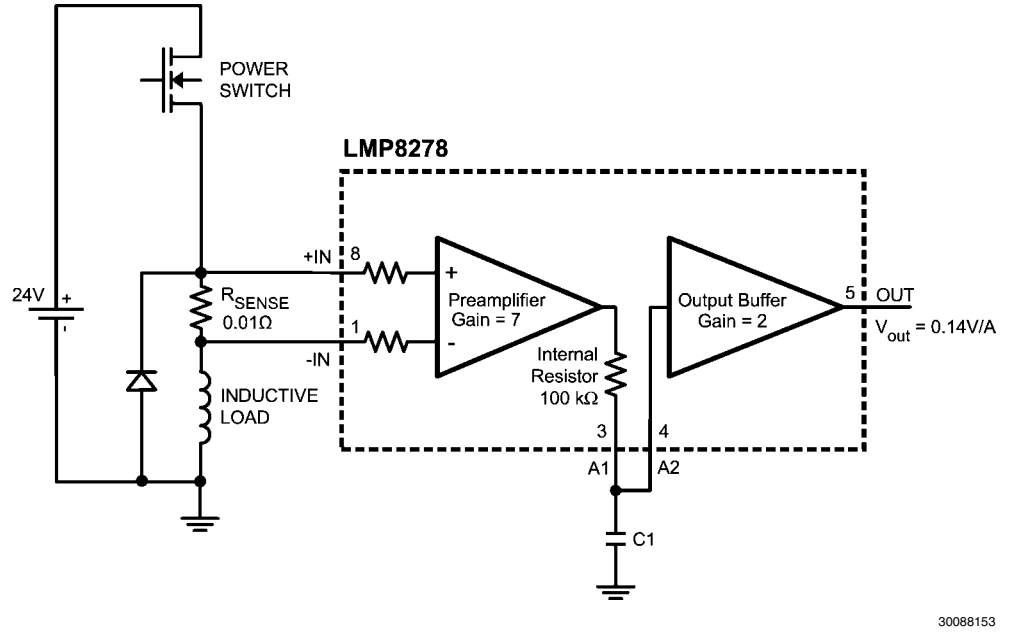


FIGURE 9. High Side Current Sensing Application

RF-PA CONTROL APPLICATION

Figure 10 illustrates how the LMP8278 can be used to monitor current flow in an RF power amplifier control application. The fact that the LMP8278 can measure small voltages at a high common mode voltage outside its own supply range makes this part a good choice for such an application. The output signal of the LMP8278 is used as an input for the PA controller. The PA controller can be used to regulate the output power of the RF-PA by measuring the output amplifier supply current.

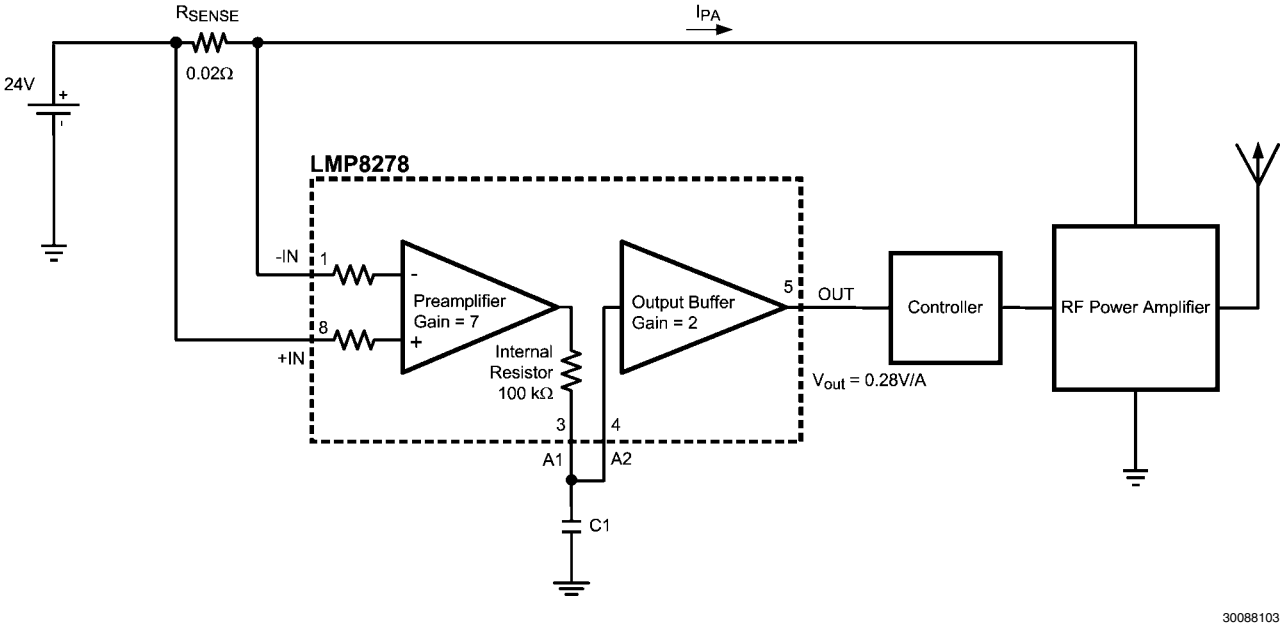
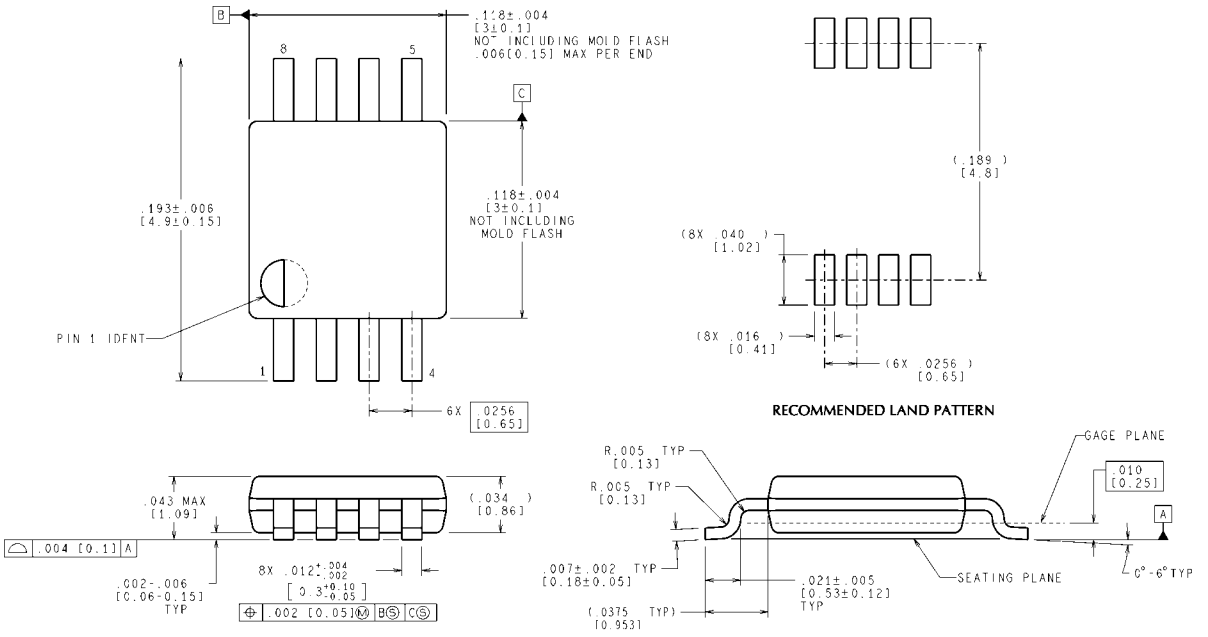


FIGURE 10. RF Power Amplifier Control Application

Physical Dimensions inches (millimeters) unless otherwise noted



CONTROLLING DIMENSION IS INCH
VALUES IN [ ] ARE MILLIMETERS

MUA08A (Rev F)

8-Pin MSOP
NS Package Number MUA08A

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