HV, Unidirectional, Current-Sense Amplifier with Comparator

Features

- Enhanced PWM Rejection
- Wide Common-Mode Voltage
  - Operational Voltage: −4 V to 80 V
  - Survival Voltage: −10 V to 85 V
- Supply Voltage: 3.0 V to 5.5 V
- Excellent CMRR
  - 150-dB DC CMRR
  - 115-dB AC CMRR at 50 kHz
- Accuracy and Zero-Drift Performance
  - 230-μV Voltage Offset (Max, −40°C to 125°C)
  - 0.3% Gain Error (Max, −40°C to 125°C)
- Bandwidth: 1 MHz (For A1, A2, A3, A4 Version)
- Slew Rate: 11.5 V/μs (For A1, A2, A3, A4 Version)
- Excellent Start-up and Power-off Response
- Gain Options for Voltage Output
  - TPA131CA1: 20 V/V
  - TPA131CA2: 50 V/V
  - TPA131CA3: 100 V/V
  - TPA131CA4: 200 V/V
  - TPA131CA5: 500 V/V
- Comparator
  - 0.6-V Internal Voltage Reference
  - Open-Drain Output with Latch Control
- −40°C to 125°C Operation Range

Applications

- Current Sensing (High-Side and Low-Side)
- Battery Chargers & Power Management
- Motor Control & Industrial Control

Description

The TPA131C is a family of high-voltage, high-side current-sense amplifiers with voltage output, internal comparator, and voltage reference. The TPA131C can sense drops across shunts at common-mode voltages from –4 V to 80 V. The TPA131C has five output voltage scales: 20 V/V, 50 V/V, 100 V/V, 200 V/V, and 500 V/V with up to 1-MHz bandwidth.

The TPA131C features one open drain comparator with internal 0.6-V references. The comparator works with a latching capability.

The TPA131C operates from single 3.0-V to 5.5-V supply, offers breakthrough performance throughout the −40°C to +125°C temperature range. It features a zero-drift core, which leads to an offset drift of 0.5 μV/°C throughout the operating temperature range and the common-mode voltage range.

The TPA131C is offered in the MSOP8 package.

Typical Application Circuit

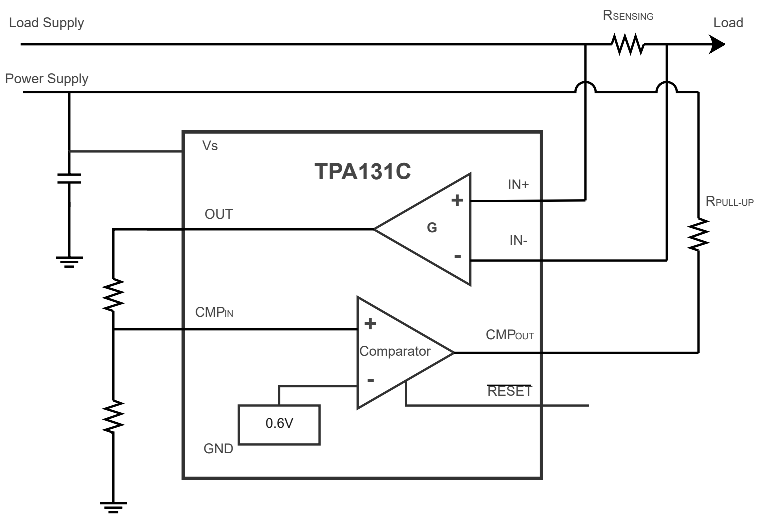


Table of Contents

Revision History

Date	Revision	Notes
2025-02-10	Rev.A.0	Initial version

Pin Configuration and Functions

TPA131C
MSOP8
Top View

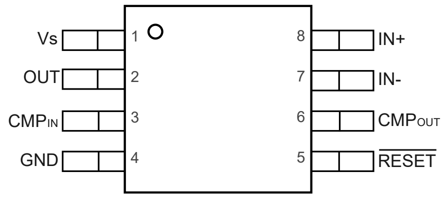


Table 1. Pin Functions: TPA131C

Pin No.	Name	I/O	Description
1	V_S		Power supply.
2	OUT	O	Output.
3	CMP_{IN}	I	Comparator input.
4	GND		Ground.
5	$\overline{RESET}$	I	Comparator reset pin, active low.
6	CMP_{OUT}	O	Comparator output.
7	IN−	I	Negative input
8	IN+	I	Positive input.

Specifications

Absolute Maximum Ratings (1)

Parameter		Min	Max	Unit
	Supply Voltage		7	V
	Input Common Voltage	−15	90	V
	Input Differential Voltage, (IN+) − (IN−)	−10	10	V
	Input Current: +IN, −IN	−10	+10	mA
T_J	Maximum Operating Junction Temperature		150	°C
T_A	Operating Temperature Range	−40	125	°C
T_{STG}	Storage Temperature Range	−65	150	°C
T_L	Lead Temperature (Soldering, 10 sec)		260	°C

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

ESD, Electrostatic Discharge Protection

Symbol	Parameter	Condition	Minimum Level	Unit
HBM	Human Body Model ESD	ANSI/ESDA/JEDEC JS-001	2	kV
CDM	Charged Device Model ESD	ANSI/ESDA/JEDEC JS-002	1.5	kV

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

Thermal Information

Package Type	θ_{JA}	θ_{JC}	Unit
MSOP8	210	45	°C/W

Electrical Characteristics

All test conditions: V_S = 3 V, T_A = 25°C, V_{SENSE} = (IN+) − (IN−), V_{CM} = (IN+) = 80 V, unless otherwise noted.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Current Sense Amplifier Input						
V_{OS}	Input Offset Voltage	V_{SENSE} = 0 mV		±20	±130	μV
		V_{SENSE} = 0 mV, T_A = −40°C to 125°C		±20	±230	μV
V_{OS} TC	Input Offset Voltage Drift	V_{SENSE} = 0 mV, T_A = −40°C to 125°C		0.15	0.5	μV/°C
V_{CM} (1)	Specified Common-Mode Input Range	V_{SENSE} = 0 mV, T_A = −40°C to 125°C	−4		80	V
	Survival Common-Mode Input Range	V_{SENSE} = 0 mV, T_A = −40°C to 125°C	−10		85	V
CMRR (2)	Common-Mode Rejection Ratio	−4 V < V_{CM} < 80 V, T_A = −40°C to 125°C	130	150		dB
I_B	Input Bias Current	V_{SENSE} = 0 mV		1	50	μA
I_{OS}	Input Offset Current	V_{SENSE} = 0 mV		0.1	1	μA
Current Sense Amplifier Noise RTI						
e_n	Input Voltage Noise Density	f = 1 kHz		80		nV/√Hz
Current Sense Amplifier Output						
G	Gain	TPA131CA1		20		V/V
		TPA131CA2		50		V/V
		TPA131CA3		100		V/V
		TPA131CA4		200		V/V
		TPA131CA5		500		V/V
GE	Gain Error	TPA131CA1, TPA131CA2, TPA131CA3, TPA131CA4		±0.05	±0.2	%
		T_A = −40°C to 125°C TPA131CA1, TPA131CA2, TPA131CA3, TPA131CA4			±0.3	%
		TPA131CA5		±0.1	±0.3	%
		T_A = −40°C to 125°C TPA131CA5			±0.5	%
	Non-Linearity Error (2)	GND + 10mV ≤ V_{OUT} ≤ V_S – 200 mV, T_A = −40°C to 125°C		±0.01		%
GE TC (2)	Gain Error vs. Temperature	T_A = −40°C to 125°C TPA131CA1, TPA131CA2, TPA131CA3		1.5	10	ppm/°C
		T_A = −40°C to 125°C TPA131CA4, TPA131CA5		1.5	12	ppm/°C
C_{LOAD}	Maxim Capacitive Load	No Oscillation		1		nF

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{OH}	Output Swing from V_S	V_S = 5.5 V, R_L= 10 kΩ to GND		8	25	mV
		V_S = 5.5 V, R_L= 10 kΩ to GND, T_A = −40°C to 125°C			30	mV
V_{OL}	Output Swing from GND	V_S = 5.5 V, R_L= 10 kΩ to GND, V_{SENSE} = 0 mV		3	15	mV
		V_S = 5.5 V, R_L = 10 kΩ to GND , V_{SENSE} = 0 mV, T_A = −40°C to 125°C			20	mV
Current Sense Amplifier Frequency Response						
BW	Bandwidth	TPA131CA1, TPA131CA2, TPA131CA3, TPA131CA4		1		MHz
		TPA131CA5		0.5		MHz
SR	Slew Rate	TPA131CA1, TPA131CA2, TPA131CA3, TPA131CA4		11.5		V/μs
		TPA131CA5		8.5		V/μs
Comparator						
VR	Internal Voltage Reference	T_A = −40°C to 125°C	580	600	630	mV
Hysteresis	Comparator Hysteresis			12		mV
IBC	Comparator Input Current	T_A = −40°C to 125°C		20		nA
VINC	Input Voltage Range (2)		0		V_S− 1.5	V
VOL	Low-level Open Drain Output	V_{CC} = 5.5 V, I_{OUT} =1 mA, T_A = −40°C to 125°C		150	300	mV
IOH	High-level Output Current	V_{CC} = 5.5 V, T_A = −40°C to 125°C		1	100	nA
TR	Respond Time			1		us
$\overline{\text{RESET}}$	Logic Input Impedance			2		MΩ
	Minimum RESET Pulse Width			1.5		us
	RESET Propagation Delay			1.1		us
Power Supply						
V_S	Supply Voltage	T_A = −40°C to 125°C	3.0		5.5	V
I_Q	Quiescent Current	V_S = 3.0 V		2.5	3	mA
		V_S = 3.0 V, T_A = −40°C to 125°C			3.1	mA
		V_S = 5.5 V		2.9	3.7	mA
		V_S = 5.5 V, T_A = −40°C to 125°C			4	mA
PSRR	Power Supply Rejection Ratio	3.0 V < V_S < 5.5 V, T_A = −40°C to 125°C	80	90		dB

(1) To keep the device safe, the common-mode voltage at both V_{IN+} and V_{IN-} must not exceed the survival common-mode input range. To guarantee the specification, common-mode voltage at both V_{IN+} and V_{IN-} should be within the specification common-mode input range.

(2) Provided by bench test and design simulation.

Typical Performance Characteristics

All test conditions: V_S = 3 V, TA = 25℃, V_{SENSE} = (IN+) − (IN−), V_{CM} = (IN+) = 80 V, unless otherwise noted.

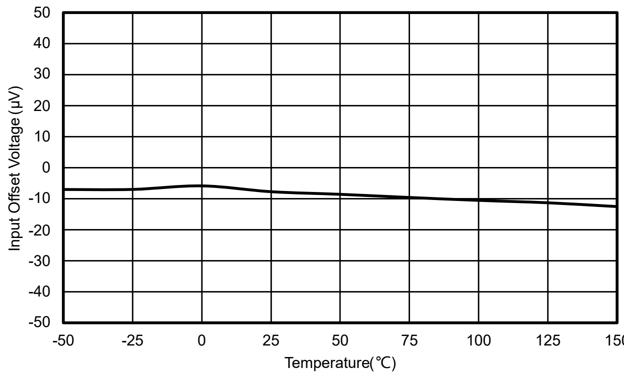


Figure 1. Offset Voltage vs. Temperature

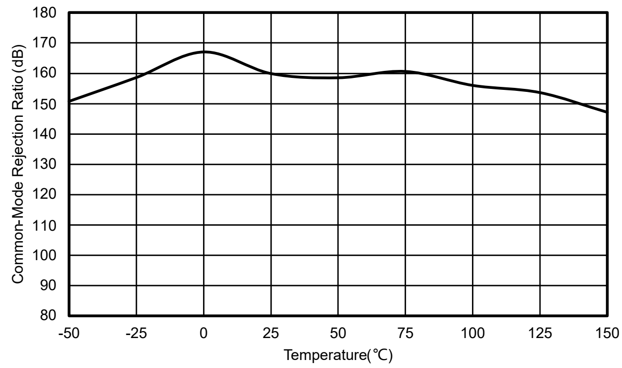


Figure 2. Common-Mode Rejection Ratio vs. Temperature

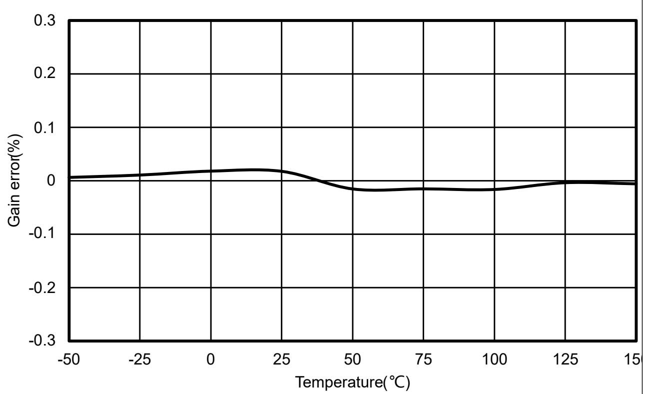


Figure 3. Gain Error vs. Temperature

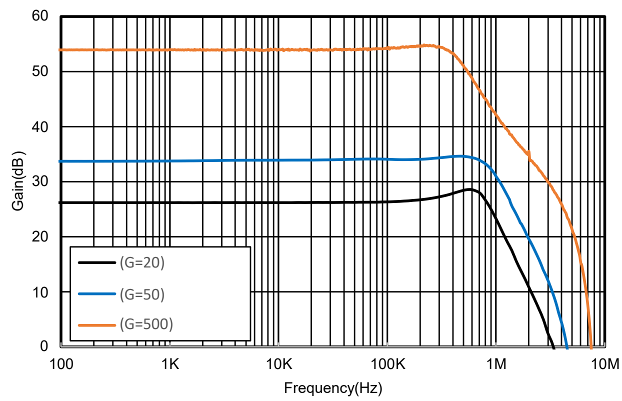


Figure 4. Gain vs. Frequency

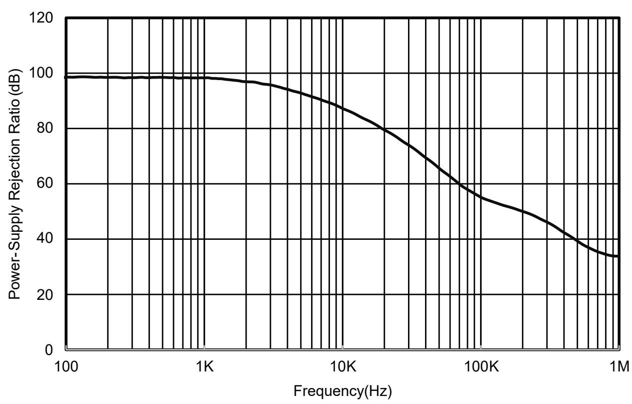


Figure 5. Power-Supply Rejection Ratio vs. Frequency

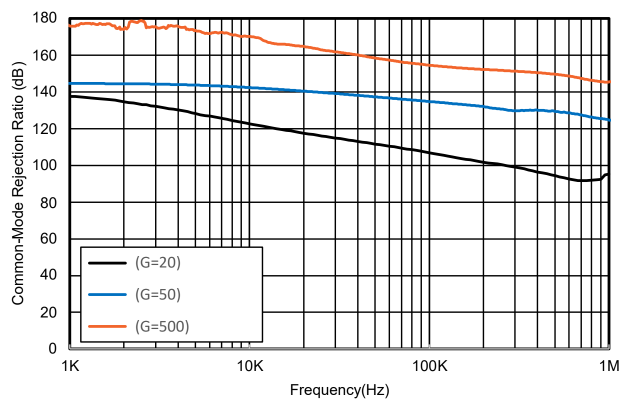


Figure 6. Common-Mode Rejection Ratio vs. Frequency

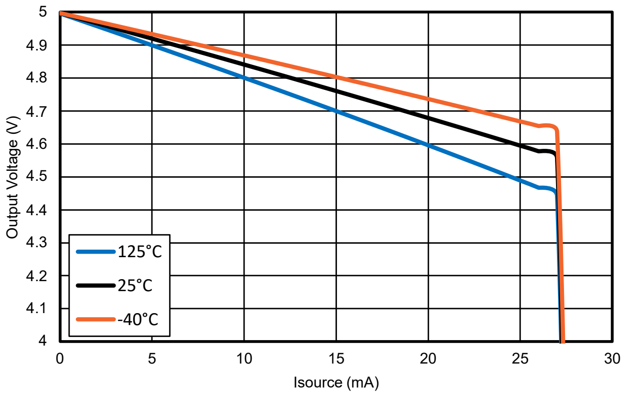


Figure 7. Output Voltage Swing vs. I_{SOURCE}

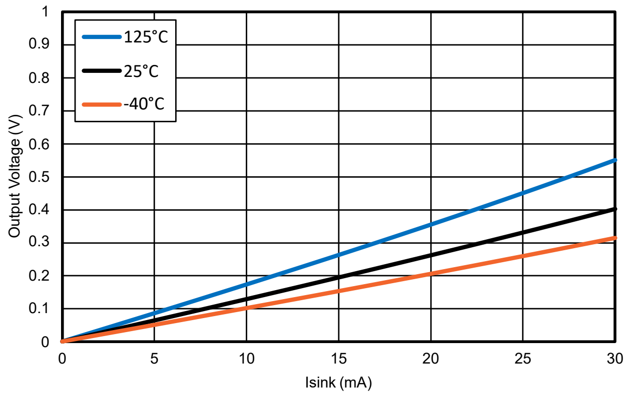


Figure 8. Output Voltage Swing vs. I_{SINK}

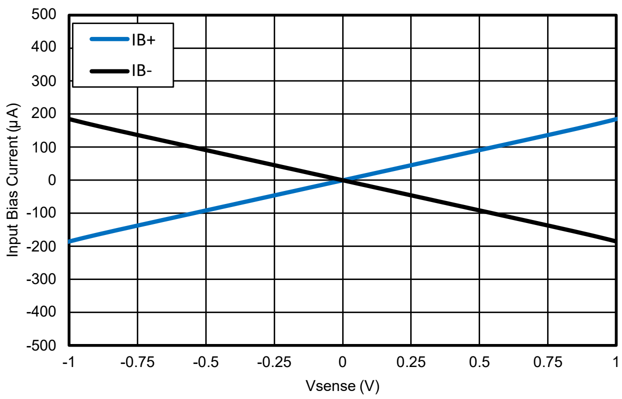


Figure 9. Input Bias Current vs. V_{SENSE}

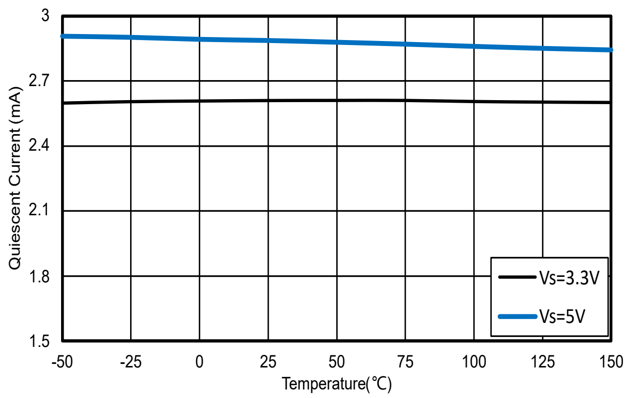


Figure 10. Quiescent Current vs. Temperature

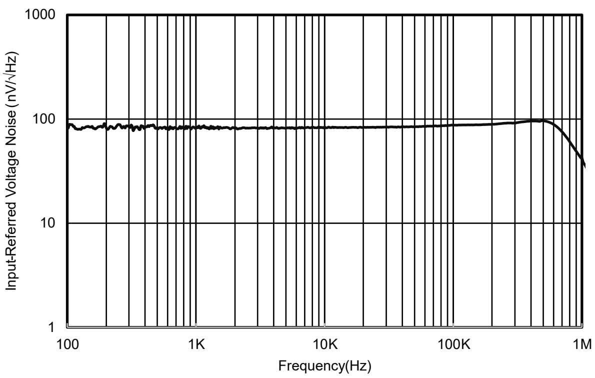


Figure 11. Input-Referred Voltage Noise vs. Frequency

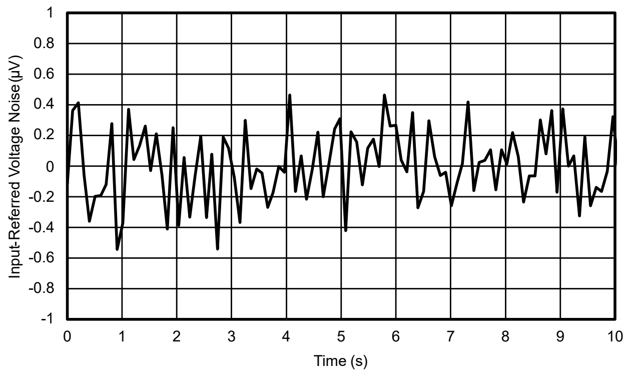


Figure 12. 0.1-Hz to 10-Hz Voltage Noise

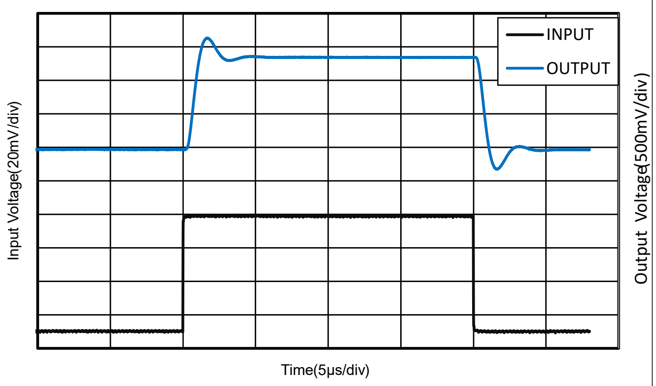
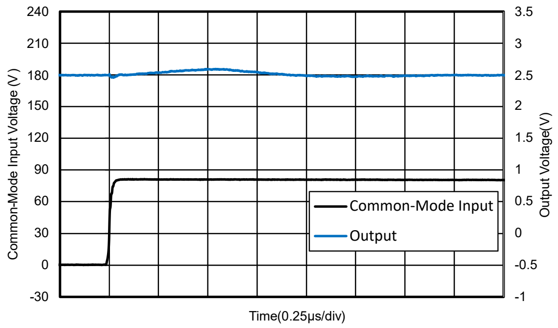
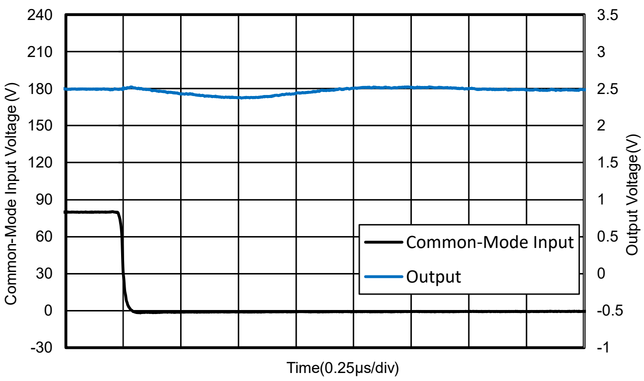


Figure 13. Step Response



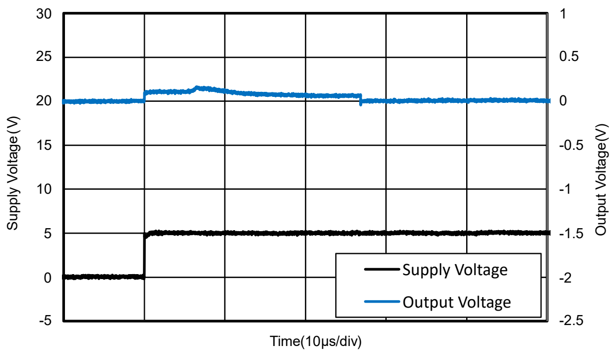
V_{CM} = 0 V to 80 V, T_{rise} = 30 ns

Figure 14. Common-Mode Voltage Transient Response



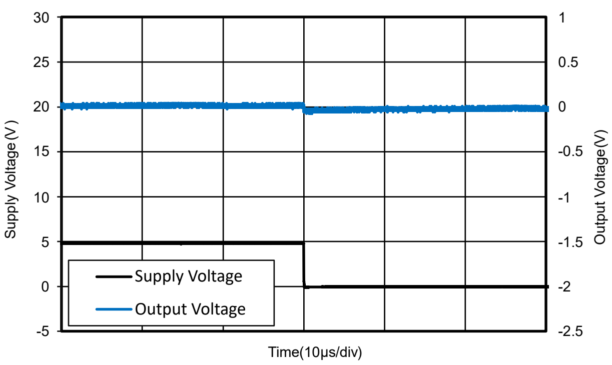
V_{CM} = 80 V to 0 V, T_{fall} = 30 ns

Figure 15. Common-Mode Voltage Transient Response



V_{CC} = 0 V to 5 V, T_{rise} = 30 ns, V_{CM} = 80 V

Figure 16. Start-Up Response



V_{CC} = 5 V to 0 V, T_{fall} = 30 ns, V_{CM} = 80 V

Figure 17. Power-Off Response

Detailed Description

Overview

The TPA131C is a high-precision current-sense amplifier with excellent CMRR. Because of its wide input common-mode voltage range, it can be used both in high-side and low-side current sensing. The TPA131C features enhanced PWM rejection, and it maintains excellent performance even when the input common mode has fast ΔV/Δt transitions. The TPA131C has a bandwidth of up to 1 MHz and an SR of 11.5 V/us, which makes it suitable for overcurrent protection and loop control systems that require a fast response speed. The TPA131C boasts exceptional performance in both start-up and power-off scenarios. Its meticulously designed output control mechanisms effectively prevent the system from triggering false alarms and ensure stability and reliability.

The TPA131C features one open drain comparator with internal 0.6-V references. The embedded comparator works with a latching capability.

Feature Description

Wide Input Common-Mode Voltage Range and Enhanced PWM Rejection

The TPA131C supports a −4-V to 80-V input common-mode voltage that is independent of the supply voltage (V_S). The ability to operate with common-mode voltages greater or less than V_S allows the TPA131C to be used in both high-side and low-side current sensing applications.

For a typical solenoid application as shown in Figure 18, when the switch is closed, the common-mode voltage across the R_{sense} swings to the battery voltage (e.g. 48 V). When the switch is open, the common-mode voltage across the R_{sense} reverses to one diode drop below ground (e.g. −0.7 V) due to the recirculation. It brings fast common-mode voltage transitions to the amplifier. The TPA131C provides excellent CMRR and enhances the PWM rejection of this application.

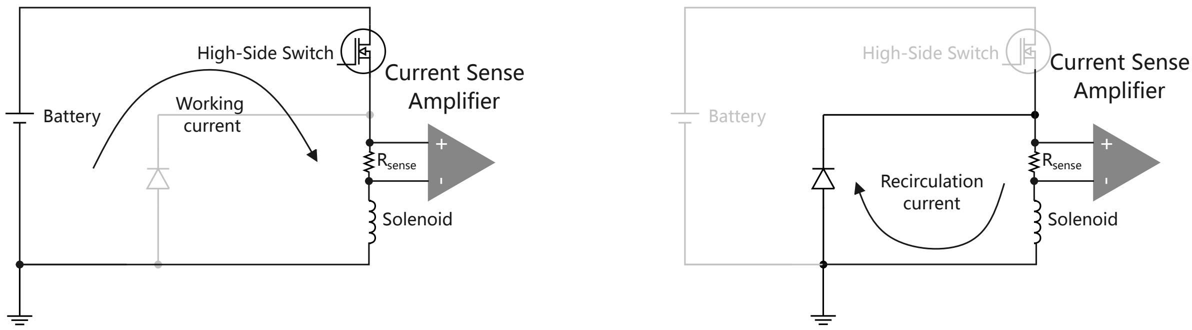


Figure 18. Solenoid Application Circuits

Internal Comparator

The TPA131C has an internal open-drain comparator, which has typically a 2-mV voltage offset and a 1-µs response time. The RESET pin resets the comparator output and the output latches.

Excellent Start-up and Power-off Response

If there is no special treatment, the output of the current-sense amplifier may generate glitches up to the supply voltage during the start-up or power-off of the device. This may cause the system to mistakenly believe that an overcurrent has occurred, leading to fault protection. Using this type of device makes the system more complex and unreliable.

The output of the TPA131C is carefully controlled during its start-up and power-off process to prevent the false triggering of the overcurrent protection, leading to increased reliability and stability. The TPA131C ensures that the output false pulse remains below 700 mV in all scenarios, including:

Various V_{CM} and V_{SENSE}: V_{CM} (common-mode voltage) and V_{SENSE} ((VIN+) − (VIN−)) are set to any voltage allowed in the Electrical Characteristics table (e.g. V_{CM} = 80 V, V_{SENSE} = 50 mV), depending on the application requirements. This enables stable operations regardless of whether the bus voltage in the system is present or not.

Various V_{CC} ramp-up and ramp-down rates: V_{CC} (supply voltage) is ramped up or ramped down at different rates ranging from nanoseconds to milliseconds. This makes the TPA131C suitable for complex industrial scenarios.

Application and Implementation

Note

Information in the following application sections is not part of the 3PEAK's component specification and 3PEAK does not warrant its accuracy or completeness. 3PEAK's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

Application Information

Selecting the Sense Resistor

The careful selection of an appropriate sense resistor is paramount in achieving accurate and reliable current measurements. To ensure the best performance, it is recommended to carefully evaluate the trade-offs between the resistance value, accuracy, power dissipation, and temperature coefficient.

When selecting a sense resistor, two primary factors should be considered: the desired current measurement range and accuracy, as well as the power dissipation in the resistor. The resistance value and tolerance must be chosen in accordance with the desired current measurement range and the required level of accuracy. Optimizing system performance often involves considering the input voltage across the sense resistor throughout its full dynamic range. However, it is crucial to note that higher resistance values contribute to increased power dissipation, potentially leading to resistor overheating. Moreover, the resistance value may also exhibit drift due to the influence of the temperature coefficient.

Recommended Component Values

Ideally, the maximum load current develops the full-scale sense voltage across the current-sense resistor. Choose the gain needed to match the maximum output voltage required for the application.

$$V_{OUT} = V_{SENSE} \cdot Gain \quad (1)$$

Where Vsense is the full-scale sense voltage, and Av is the gain of the TPA131C. In applications of monitoring a high current, ensure that Rsense is able to dissipate its own I^2R power loss. If the resistor's power dissipation exceeds the nominal value, the value may drift or fail altogether. The TPA131C senses a wide variety of currents with different sense-resistor values.

Input Filter

The input signal of the TPA131C is sampled by the switch capacitor with a frequency of about 8 MHz.

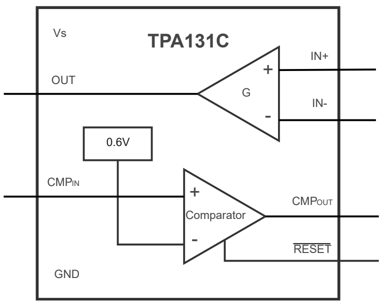


Figure 19. Brief Circuit Diagram of TPA131C

According to the Nyquist Sampling Theorem, under-sampling may lead to aliasing. When the noise with a frequency greater than 1/2 * FCLK (4 MHz) is present, it may be aliased to lower frequencies by the sampling structure, interfering with the effective signal.

Therefore, it is highly recommended to include an anti-alias filter at the input of the TPA131C. A common first-order RC low-pass filter is shown in Figure 20.

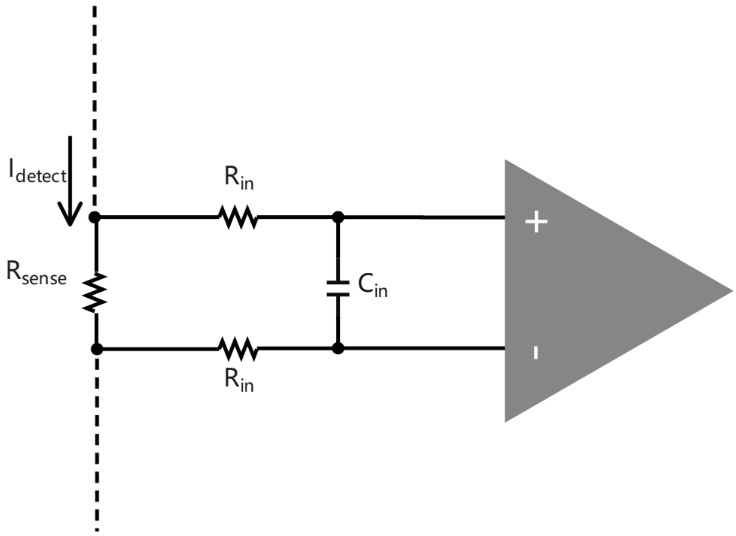


Figure 20. Input Filter Circuit

The bandwidth of the system with filtering can be calculated using Equation 2:

$$BW_{Filter} = \frac{1}{2\pi\,(2 \cdot R_{in})\,C_{in}} \tag{2}$$

However, it is crucial to be aware of the potential side effects of input filtering. The input resistance R_{in} plays a role in the voltage division with the chip's differential impedance R_{diff} (5.6 kΩ ±15% for the TPA131C), which can introduce an additional gain error:

$$\text{Gain Error} = \frac{2\,R_{in}}{2\,R_{in} + R_{diff}} \tag{3}$$

In general, we have the following suggestions for the input of the TPA131C:

1. Add an anti-alias low-pass filter with a cutoff frequency equal to or less than the bandwidth of the TPA131C (1 MHz).
2. To reduce the gain error, it is recommended that R_{in} is less than or equal to 10 Ω if the system is not calibrated.

Typical Application

Figure 21 shows the typical application schematic.

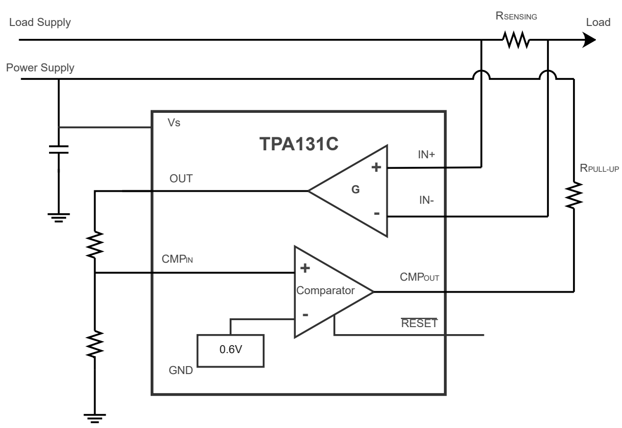


Figure 21. Typical Application Circuit

Layout

Layout Guideline

- When working with high currents through the R_{SENSE} resistor, it's crucial to minimize the errors caused by the solder and parasitic trace resistance. The four-terminal current sense resistor or the Kelvin (force and sense) PCB layout is recommended to ensure accurate current sensing and optimal performance of the TPA131C.
- Ensure that the sense resistor has ample copper trace area to effectively dissipate heat. This minimizes temperature-induced changes in the value of the resistor and maintains measurement accuracy.
- Place a 0.1-μF bypass capacitor as close as possible to the supply and ground pins of the TPA131C. This minimizes the impact of noise and impedance on the power supply and ensures stable operation.
- Place a low-pass filter as close as possible to the input pins of the TPA131C. This effectively avoids aliasing and improves measurement accuracy.

Layout Example

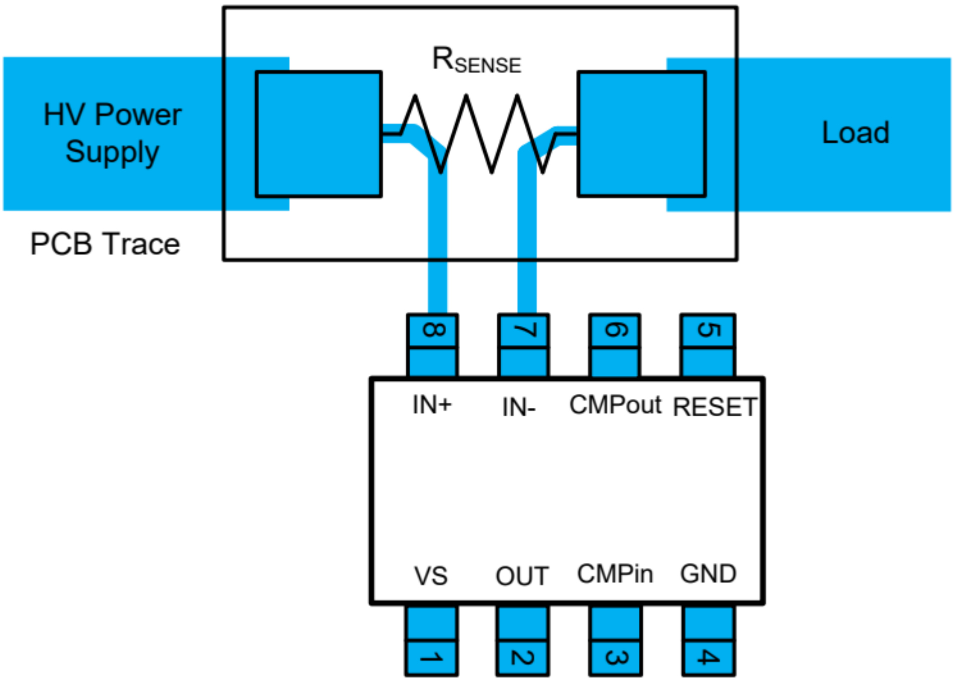
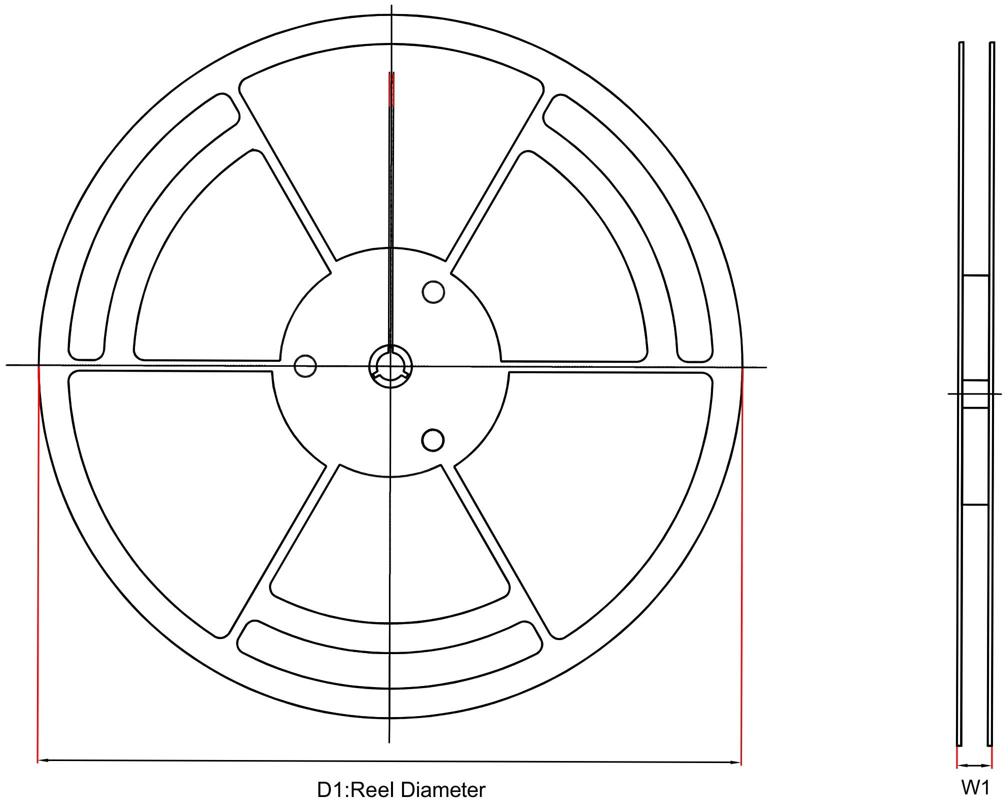
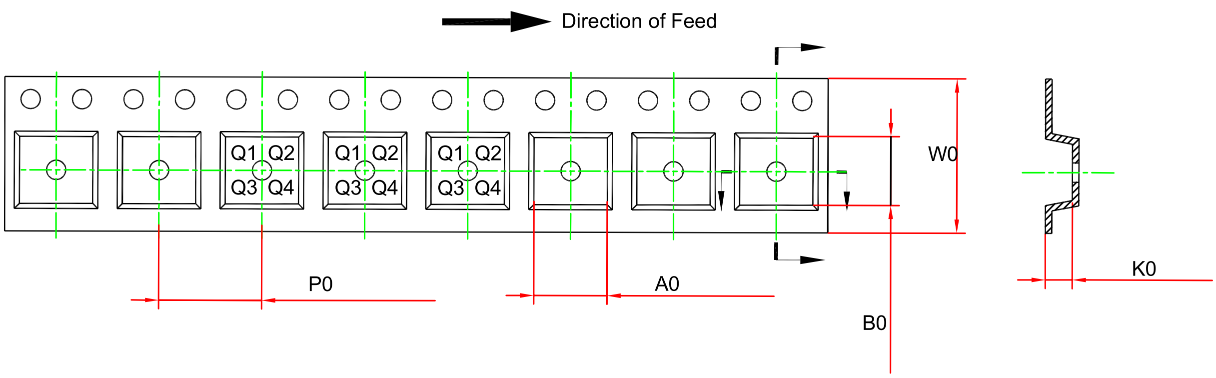


Figure 22. Recommended Layout

Tape and Reel Information



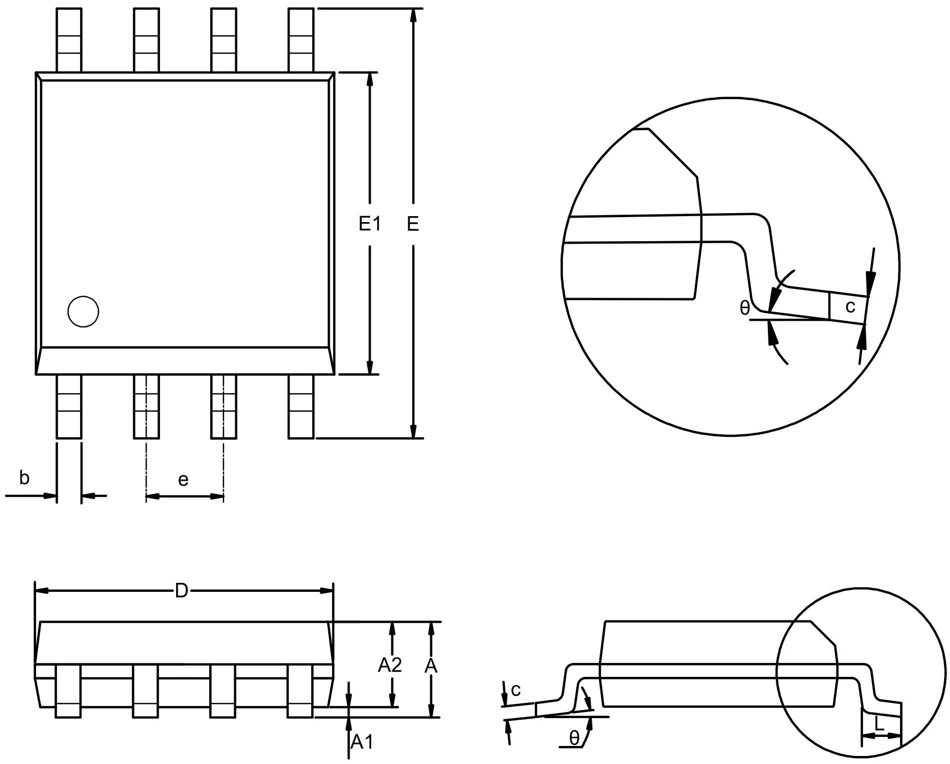


Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TPA131CAx-VS1R-S	MSOP8	330	17.6	5.3	3.4	1.3	8	12	Q1

Package Outline Dimensions

MSOP8

Package Outline Dimensions VS1(MSOP-8-A)



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.800	1.100	0.031	0.043
A1	0.020	0.150	0.001	0.006
A2	0.750	0.950	0.030	0.037
b	0.250	0.380	0.010	0.015
c	0.090	0.230	0.004	0.009
D	2.900	3.100	0.114	0.122
E	4.700	5.100	0.185	0.201
E1	2.900	3.100	0.114	0.122
e	0.650 BSC		0.026 BSC	
L	0.400	0.800	0.016	0.031
θ	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

Order Information

Order Number	Gain	Package	Marking Information	MSL	Transport Media, Quantity	Eco Plan
TPA131CA1-VS1R-S	20 V/V	MSOP8	1CA1	MSL1	Tape and Reel, 3,000	Green
TPA131CA2-VS1R-S (1)	50 V/V	MSOP8	1CA2	MSL1	Tape and Reel, 3,000	Green
TPA131CA3-VS1R-S (1)	100 V/V	MSOP8	1CA3	MSL1	Tape and Reel, 3,000	Green
TPA131CA4-VS1R-S (1)	200 V/V	MSOP8	1CA4	MSL1	Tape and Reel, 3,000	Green
TPA131CA5-VS1R-S (1)	500 V/V	MSOP8	1CA5	MSL1	Tape and Reel, 3,000	Green

(1) For future products, contact the 3PEAK factory for more information and samples.

Green: 3PEAK defines "Green" to mean RoHS compatible and free of halogen substances.

IMPORTANT NOTICE AND DISCLAIMER

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