Unidirectional, Current-Sense Amplifier with PWM Rejection

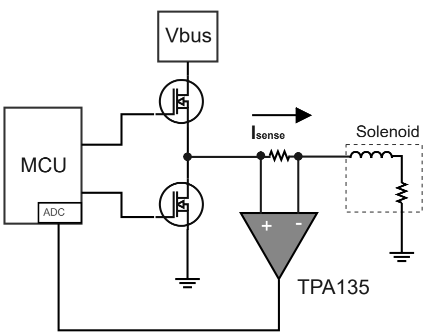
Features

- 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
  - 140-μV Voltage Offset (Max, −40°C to 125°C)
  - 0.35% Gain Error (Max, −40°C to 125°C)
- Bandwidth: 1 MHz (For A1, A2, A3, A4 Version)
- Excellent Start-up and Power-off Response
- Gain Options for Voltage Output
  - TPA135A1: 20 V/V
  - TPA135A2: 50 V/V
  - TPA135A3: 100 V/V
  - TPA135A4: 200 V/V
  - TPA135A5: 500 V/V
- −40°C to 125°C Operation Range

Applications

- Current Sensing (High-Side and Low-Side)
- Power Management
- Solenoid and Valve Control
- Motor Control

Typical Application Circuit



Description

The TPA135 is a unidirectional current-sense amplifier which has a very wide input common-mode voltage range from −4 V to 80 V with a high bandwidth of 1 MHz. The enhanced PWM rejection allows the TPA135 to accommodate the solenoids and motors applications. The device features high precision accuracy specifications of Vos and the gain error, which makes it ideal for small signal conditioning. Its high bandwidth makes it ideal not only for DC current measurement, but also for high-speed applications like fast overcurrent protection.

Fixed gains are optional: 20 V/V, 50 V/V, 100 V/V, 200 V/V, and 500 V/V. The device offers breakthrough performance throughout the temperature range of −40°C to +125°C. The device is offered SOT23-5 package.

Many systems, including motors and solenoids, employ PWM signals for modulation or control purposes. However, these PWM signals generate fast common-mode voltage transitions that oscillate between high voltage and ground potential. This can pose a challenge for the current measurement circuitry, as it may result in undesirable output voltage fluctuations. To address this issue, the device incorporates an advanced PWM rejection feature. This feature minimizes the impact of common-mode voltage transitions and ensures stable and reliable output voltage.

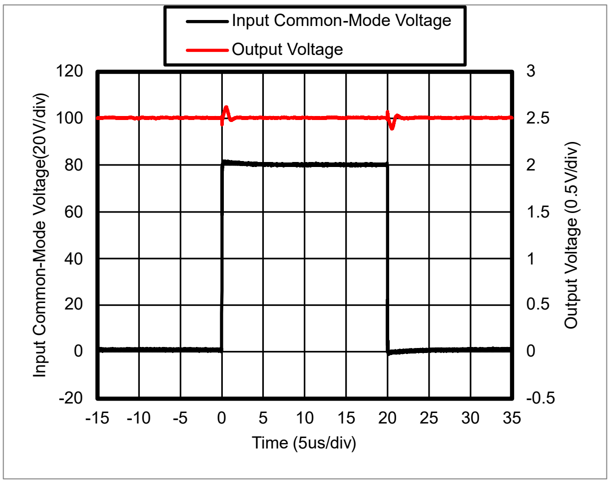


Figure 1. Enhanced PWM Rejection Function

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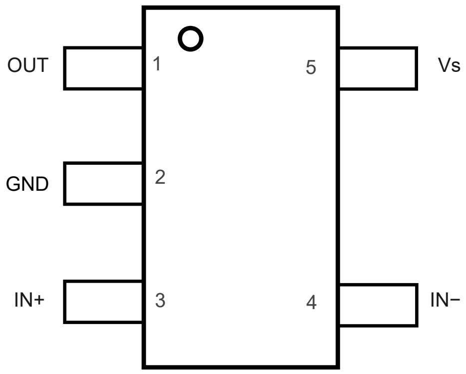
Revision History

Date	Revision	Notes
2024-08-30	Rev.A.0	Initial version.
2024-11-14	Rev.A.1	Updated specifications: • Modified the MSL level from "MSL1" to "MSL3". • Updated thermal information. • Modified minimum CMRR from "130 dB" to "128 dB", modified typical Vos to 30 μV. • Added new orderable part number "TPA135A2-S5TR-S" and "TPA135B2-S5TR-S". • Updated the Tape and Reel Information.

Pin Configuration and Functions

TPA135Ax
SOT23-5
Top View



TPA135Bx
SOT23-5
Top View

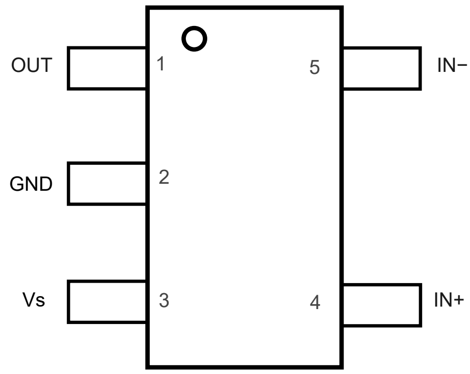


Table 1. Pin Functions: TPA135

Pin No.		Name	I/O	Description
TPA135Ax	**TPA135Bx**			
1	1	OUT	O	Output voltage.
2	2	GND		Ground.
3	4	IN+	I	Noninverting input.
4	5	IN−	I	Inverting input.
5	3	V_S		Power supply, 3 V to 5.5 V.

Specifications

Absolute Maximum Ratings (1)

Parameter		Min	Max	Unit
	Supply Voltage		6	V
	Input Common Voltage	−15	90	V
	Input Differential Voltage, (IN+) − (IN−)		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

Thermal Information

Package Type	θ_{JA}	θ_{JC}	Unit
SOT23-5	158	61	°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
Input						
V_{OS}	Input Offset Voltage	V_{SENSE} = 0 mV, T_A = −40°C to 125°C		±30	±140	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	128	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
Noise RTI						
e_n	Input Voltage Noise Density	f = 1 kHz		80		nV/√Hz
Output						
G	Gain	TPA135x1		20		V/V
		TPA135x2		50		V/V
		TPA135x3		100		V/V
		TPA135x4		200		V/V
		TPA135x5		500		V/V
GE	Gain Error	TPA135x1, TPA135x2, TPA135x3, TPA135x4		±0.05	±0.2	%
		T_A = −40°C to 125°C TPA135x1, TPA135x2, TPA135x3, TPA135x4			±0.35	%
		TPA135x5		±0.1	±0.3	%
		T_A = −40°C to 125°C TPA135x5			±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 TPA135x1, TPA135x2, TPA135x3		1.5	10	ppm/°C
		T_A = −40°C to 125°C TPA135x4, TPA135x5		1.5	12	ppm/°C
C_{LOAD}	Maxim Capacitive Load	No Oscillation		1		nF
V_{OH}	Output Swing from V_S	V_S = 5.5 V, R_L= 10 kΩ to GND		8	25	mV

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
		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
Frequency Response						
BW	Bandwidth	TPA135x1, TPA135x2, TPA135x3, TPA135x4		1		MHz
		TPA135x5		0.5		MHz
SR	Slew Rate	TPA135x1, TPA135x2, TPA135x3, TPA135x4		11.5		V/µs
		TPA135x5		8.5		V/µs
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	89	105		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°C, V_{SENSE} = (IN+) − (IN−), V_{CM} = (IN+) = 80 V, unless otherwise noted.

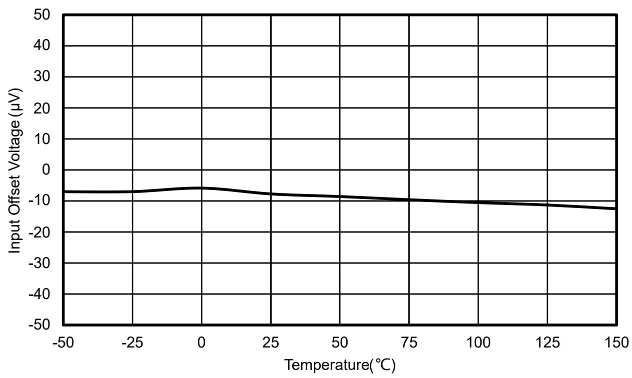


Figure 2. Offset Voltage vs. Temperature

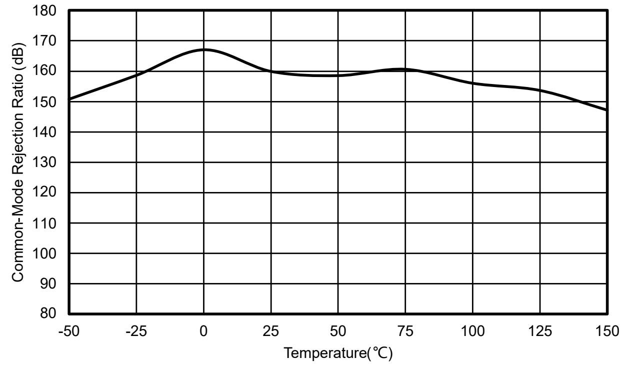


Figure 3. Common-Mode Rejection Ratio vs. Temperature

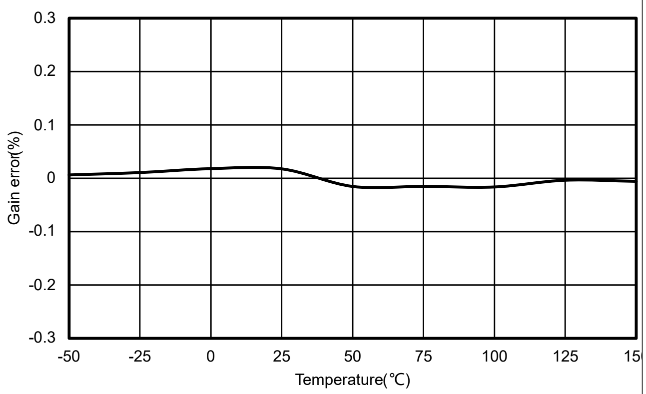


Figure 4. Gain Error vs. Temperature

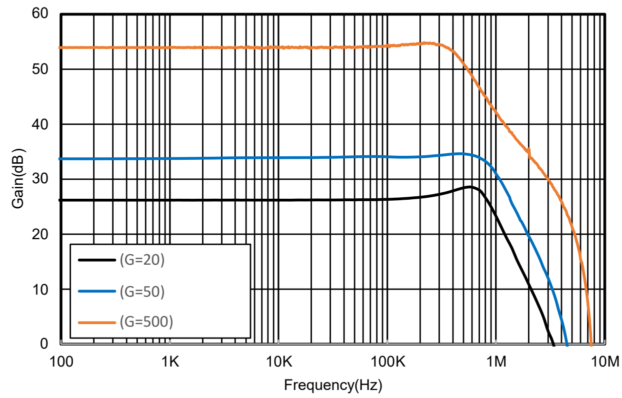


Figure 5. Gain vs. Frequency

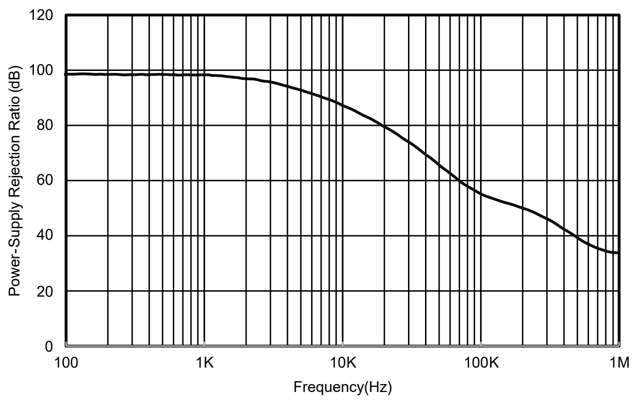


Figure 6. Power-Supply Rejection Ratio vs. Frequency

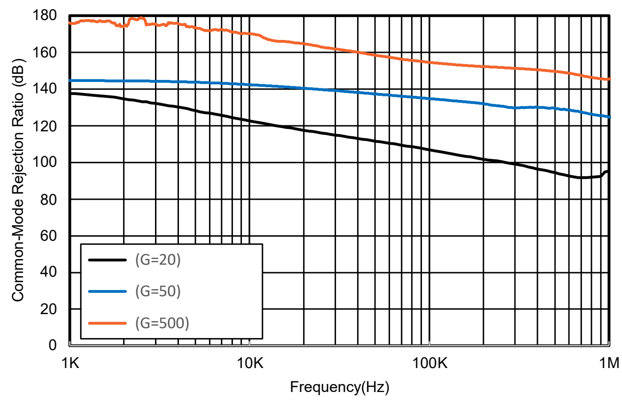


Figure 7. Common-Mode Rejection Ratio vs. Frequency

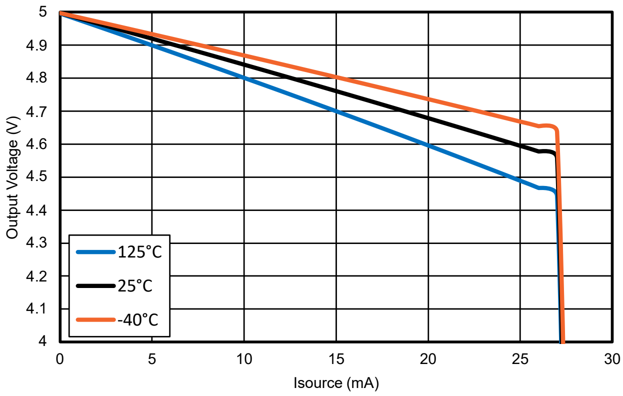


Figure 8. Output Voltage Swing vs. I_{SOURCE}

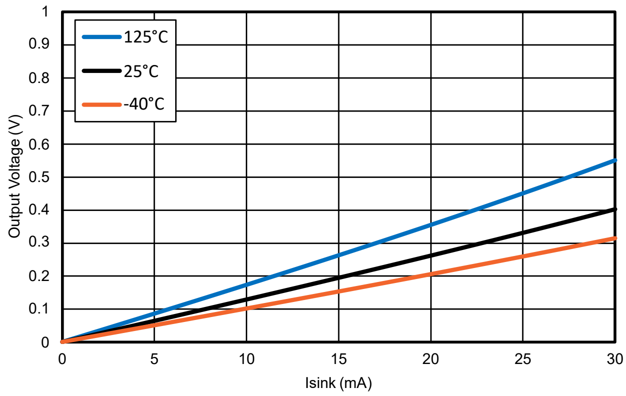


Figure 9. Output Voltage Swing vs. I_{SINK}

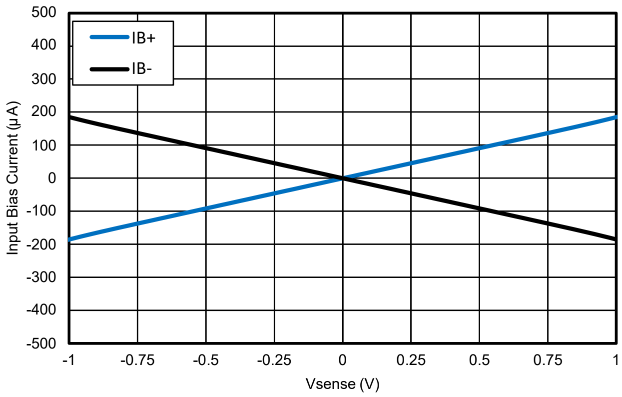


Figure 10. Input Bias Current vs. V_{SENSE}

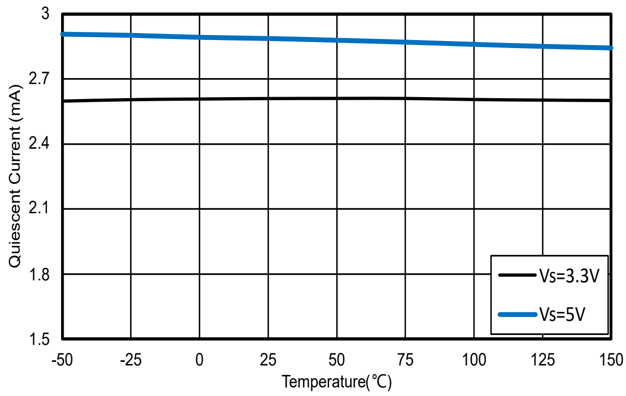


Figure 11. Quiescent Current vs. Temperature

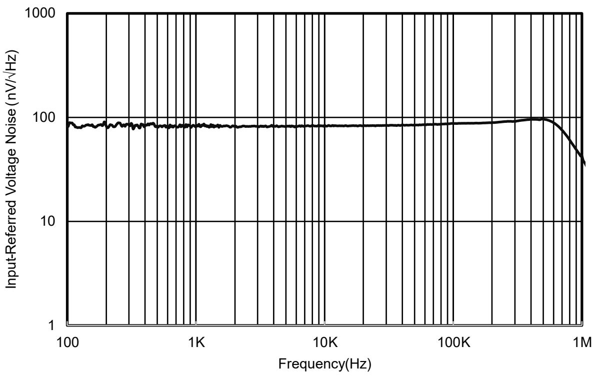


Figure 12. Input-Referred Voltage Noise vs. Frequency

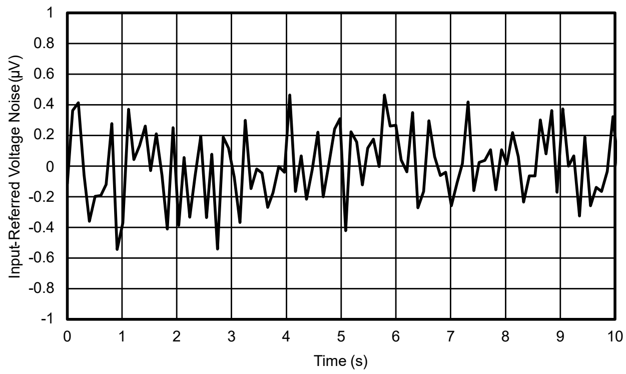


Figure 13. 0.1-Hz to 10-Hz Voltage Noise

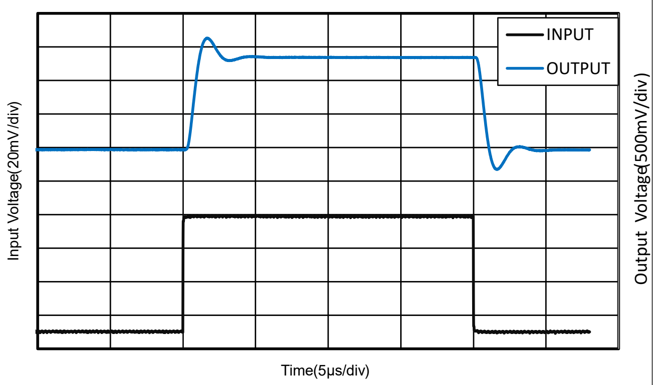
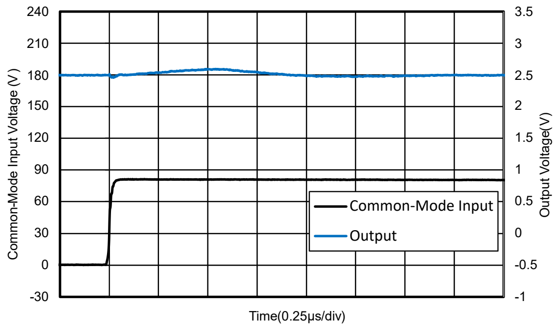
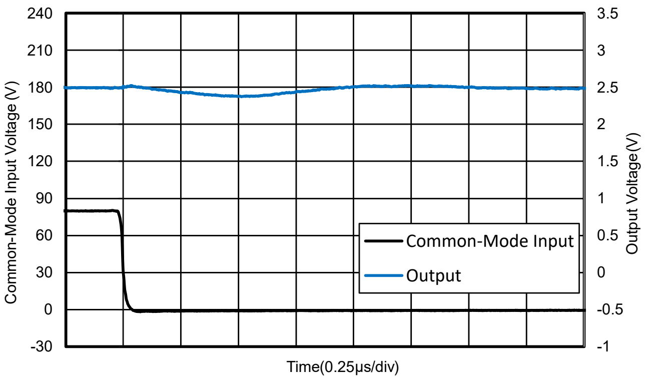


Figure 14. Step Response



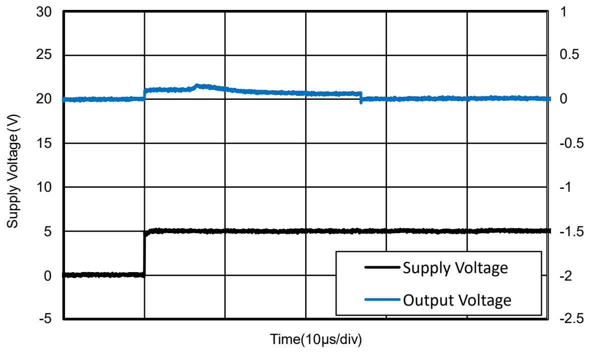
V_{CM} = 0 V to 80 V, T_{rise} = 30 ns

Figure 15. Common-Mode Voltage Transient Response



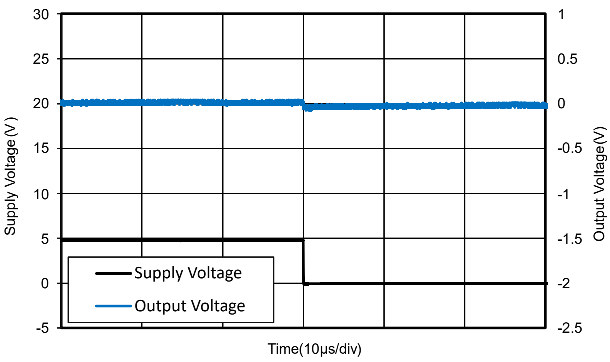
V_{CM} = 80 V to 0 V, T_{fall} = 30 ns

Figure 16. Common-Mode Voltage Transient Response



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

Figure 17. Start-Up Response



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

Figure 18. Power-Off Response

Detailed Description

Overview

The TPA135 is a high-precision current-sense amplifier with excellent CMRR. Because of its wide input common-mode voltage range, it can be used in both the high-side and low-side current sensing. The TPA135 features enhanced PWM rejection, and it maintains an excellent performance even when the input common mode has fast ΔV/Δt transitions. The TPA135 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 TPA135 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.

Feature Description

Wide Input Common-Mode Voltage Range and Enhanced PWM Rejection

The TPA135 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 TPA135 to be used both in high-side and low-side current-sensing applications.

For a typical solenoid application as shown in Figure 19, 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 TPA135 provides excellent CMRR and enhances the PWM rejection of this application.

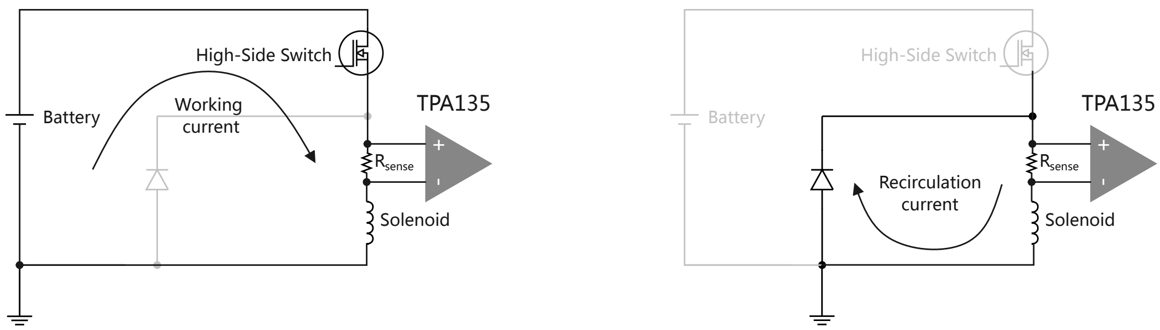


Figure 19. Solenoid Application Circuits

Unidirectional Application Schematic

The TPA135 measures the differential voltage generated when current flows through a resistor, which is often referred to as a shunt resistor. The TPA135 operates only in unidirectional mode, which means that it can only detect current from the power supply to the system load.

The linear range of the output stage is limited by how close to ground the output voltage is under zero-input conditions. Be sure to apply a differential input voltage of (VOL/gain) or higher to keep the TPA135 outputs in the linear operating region.

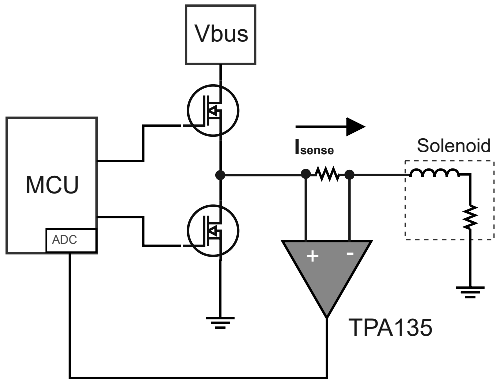


Figure 20. Unidirectional Application Schematic

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 TPA135 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 TPA135 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 TPA135 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.

Input Filter

The input signal of the TPA135 is sampled by the switch capacitor with a frequency of about 8 MHz, as shown in Figure 21.

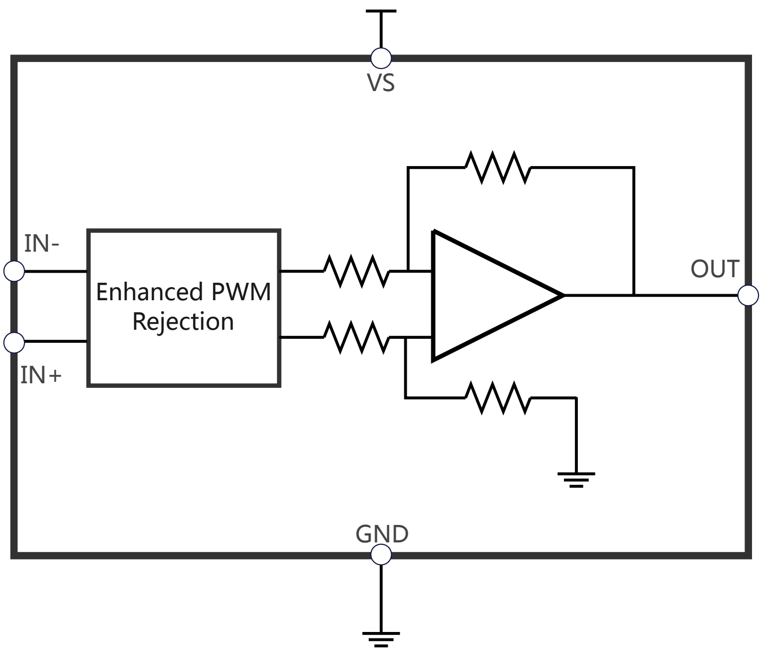


Figure 21. Brief Circuit Diagram of TPA135

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 TPA135. A common first-order RC low-pass filter is shown in Figure 22.

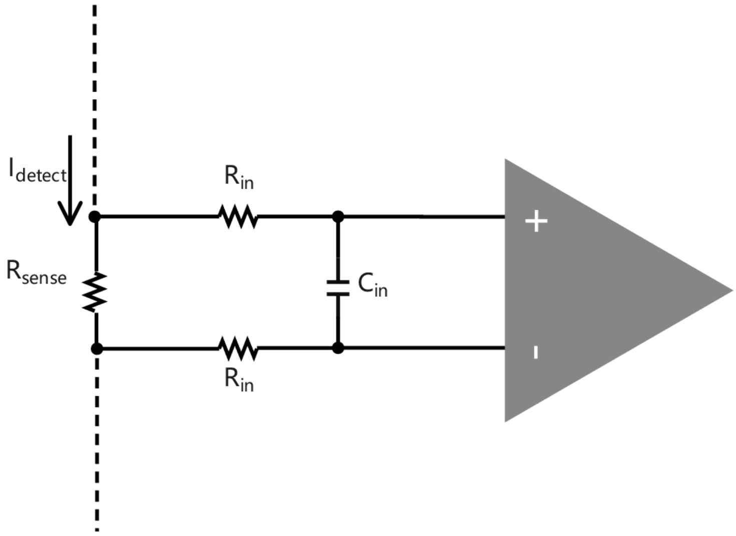


Figure 22. Input Filter Circuit

The bandwidth of the system with filtering can be calculated using Equation 1:

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

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 TPA135), which can introduce an additional gain error:

$$\text{Gain Error} = \frac{2\,R_{in}}{2\,R_{in} + R_{diff}} \qquad (2)$$

In general, we have the following suggestions for the input of the TPA135:

1. Add an anti-alias low-pass filter with a cutoff frequency equal to or less than the bandwidth of the TPA135 (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.

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 TPA135.
- Ensure that the sense resistor has the ample copper trace area to effectively dissipate heat. This minimizes temperature-induced changes in the value of the resistor and maintains the measurement accuracy.
- Place a 0.1-μF bypass capacitor as close as possible to the supply and ground pins of the TPA135. 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 TPA135. This effectively avoids aliasing and improves measurement accuracy.

Layout Example

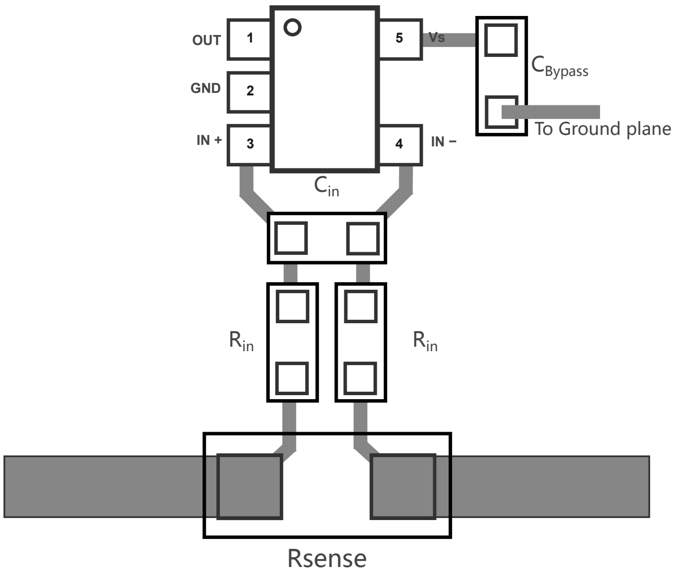


Figure 23. TPA135Ax Recommended Layout

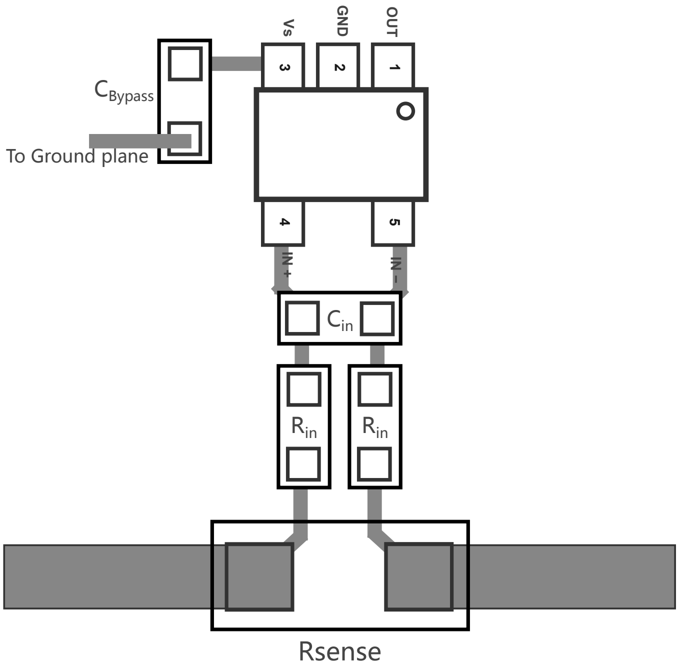
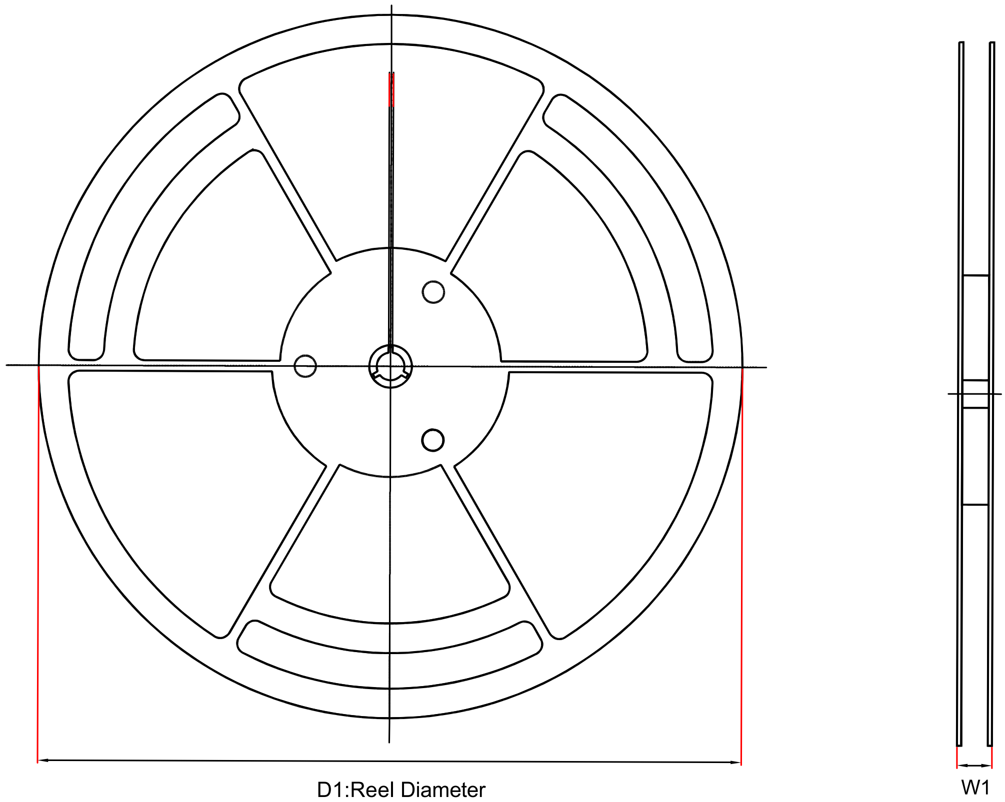
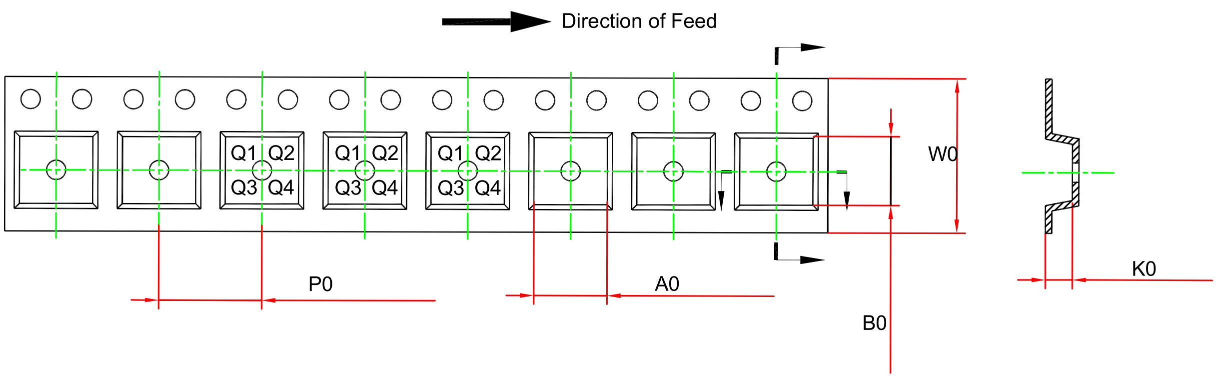


Figure 24. TPA135Bx Recommended Layout

Tape and Reel Information





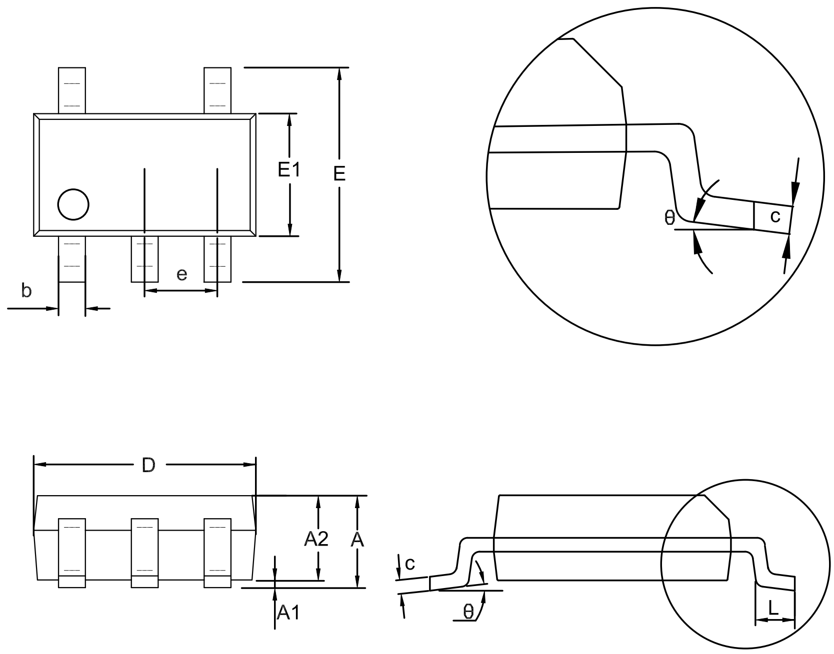
Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm) (1)	B0 (mm) (1)	K0 (mm) (1)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TPA135Ax-S5TR-S	SOT23-5	180	12	3.3	3.25	1.4	4	8	Q3
TPA135Bx-S5TR-S	SOT23-5	180	12	3.3	3.25	1.4	4	8	Q3

(1) The value is for reference only. Contact the 3PEAK factory for more information.

Package Outline Dimensions

SOT23-5

Package Outline Dimensions S5T(SOT23-5-A)



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	1.050	1.250	0.041	0.049
A1	0.000	0.150	0.000	0.006
A2	1.000	1.200	0.039	0.047
b	0.280	0.500	0.011	0.020
c	0.100	0.230	0.004	0.009
D	2.820	3.020	0.111	0.119
E	2.600	3.000	0.102	0.118
E1	1.500	1.720	0.059	0.068
e	0.950 BSC		0.037 BSC	
L	0.300	0.600	0.012	0.024
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
TPA135A1-S5TR-S (1)	20 V/V	SOT23-5	5A1	MSL3	Tape and Reel, 3,000	Green
TPA135A2-S5TR-S	50 V/V	SOT23-5	5A2	MSL3	Tape and Reel, 3,000	Green
TPA135A3-S5TR-S	100 V/V	SOT23-5	5A3	MSL3	Tape and Reel, 3,000	Green
TPA135A4-S5TR-S	200 V/V	SOT23-5	5A4	MSL3	Tape and Reel, 3,000	Green
TPA135A5-S5TR-S (1)	500 V/V	SOT23-5	5A5	MSL3	Tape and Reel, 3,000	Green
TPA135B1-S5TR-S (1)	20 V/V	SOT23-5	5B1	MSL3	Tape and Reel, 3,000	Green
TPA135B2-S5TR-S	50 V/V	SOT23-5	5B2	MSL3	Tape and Reel, 3,000	Green
TPA135B3-S5TR-S	100 V/V	SOT23-5	5B3	MSL3	Tape and Reel, 3,000	Green
TPA135B4-S5TR-S	200 V/V	SOT23-5	5B4	MSL3	Tape and Reel, 3,000	Green
TPA135B5-S5TR-S (1)	500 V/V	SOT23-5	5B5	MSL3	Tape and Reel, 3,000	Green

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

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

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