3-V to 150-V V_{CM}, 1 MHz, High-Precision, Current-Sense Amplifier

Features

- Voltage Offset: ±150 µV (Max)
- Wide Common-Mode Voltage: 3.0 V to 150 V
- Supply Voltage: 3.0 V to 20 V
- Accuracy and Zero-Drift Performance:
  - 0.55% Gain Error (Max over Temperature)
  - 20-ppm/°C Gain Drift (Max over Temperature)
  - 0.1-µV/°C Offset Drift (Typ)
- Multiple Gain Options for Voltage Output:
  - TPA158x1: 20 V/V
  - TPA158x2: 50 V/V
  - TPA158x3: 100 V/V
  - TPA158x4: 200 V/V
  - TPA158x5: 500 V/V
- High Bandwidth: 1 MHz (TPA158x1, x2, x3, x4)
- Rail-to-Rail Output
- Industrial Operation Range: –40°C to 125°C

Applications

- Current Sensing (High-Side)
- Battery Chargers
- Power Management
- Automotive
- Server Backplanes
- Base Stations and Telecom Equipment
- Industrial Control and Automation

Description

The TPA158 is a series of high-side current-sense amplifiers with high common voltage. The TPA158 series has very high precision and accuracy specifications of V_{OS} less than 150 µV (max) and gain error less than 0.55% (max). Five fixed gains are available: 20 V/V, 50 V/V, 100 V/V, 200 V/V, and 500 V/V. These options provide a wide dynamic range for current-sensing applications.

The TPA158 series features an input common-mode voltage range from 3 V to 150 V with 1-MHz bandwidth, which makes it ideal for small-signal conditioning interfacing with a SAR ADC.

The TPA158 offers breakthrough performance throughout the −40°C to +125°C temperature range. It features a zero-drift core, which leads to a maximum offset drift of 0.1µV/°C throughout the operating temperature range and the common-mode voltage range. The TPA158 is offered in the SOT23-5 package.

Functional Block Diagram

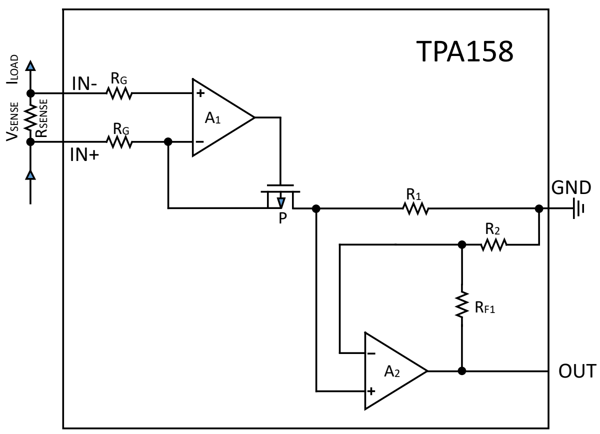


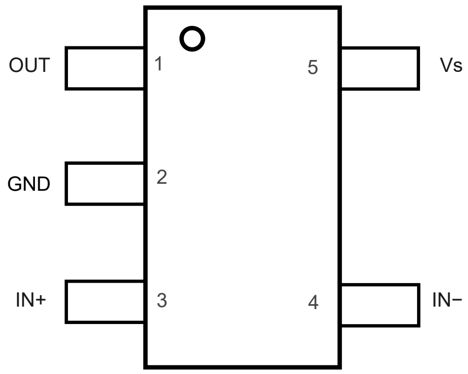
Table of Contents

Revision History

Date	Revision	Notes
2024-12-09	Rev.A.0	Initial version

Pin Configuration and Functions

TPA158Ax
SOT23-5
Top View



TPA158Bx
SOT23-5
Top View

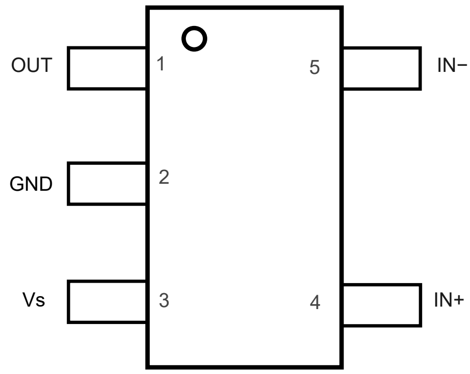


Table 1. Pin Functions: TPA158

Pin No.		Name	I/O	Description
TPA158Ax	TPA158Bx			
1	1	OUT	O	Output voltage.
2	2	GND		Ground.
3	4	IN+	I	Non-inverting input.
4	5	IN−	I	Inverting input.
5	3	V_S		Power supply.

Specifications

Absolute Maximum Ratings (1)

Parameter		Min	Max	Unit
	Supply Voltage	–0.3	22	V
	Input Common Voltage	–0.3	160	V
	Input Current: +IN, –IN	−10	10	mA
T_A	Operating Temperature Range	−40	125	°C
T_J	Maximum Junction Temperature		150	°C
T_{STG}	Storage Temperature Range	−65	150	°C
T_L	Lead Temperature (Soldering, 10 sec)		300	°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 (1)	2	kV
CDM	Charged Device Model ESD	ANSI/ESDA/JEDEC JS-002 (2)	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
SOT23-5	161	64	°C/W

Electrical Characteristics

All test conditions: T_A = 25°C, V_S = 5 V, V_{SENSE} = V_{IN+} – V_{IN-} = 0.5 V / Gain, V_{CM} = V_{IN-} = 48 V, unless otherwise noted.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Input						
V_{OS}	Input Offset Voltage	T_A = 25°C		±15	±100	μV
		T_A = −40°C to 125°C		±15	±150	μV
V_{OS} TC (1)	Input Offset Voltage Drift	T_A = −40°C to 125°C		0.1	0.5	μV/°C
V_{CM}	Common-Mode Input Range	T_A = −40°C to 125°C	3		150	V
CMRR	Common-Mode Rejection Ratio	T_A = −40°C to 125°C, 3.0 V < V_{CM} < 120 V	120	140		dB
I_B	Input Bias Current	V_{SENSE} = 0 mV, T_A = −40°C to 125°C		90	115	μA
I_{OS}	Input Offset Current	V_{SENSE} = 0 mV, T_A = −40°C to 125°C		±0.1		μA
Noise RTI (2)						
e_n (1)	Input Voltage Noise Density	f = 10 kHz		50		nV/√Hz
Output						
G	Gain	TPA158A1		20		V/V
		TPA158A2		50		V/V
		TPA158A3		100		V/V
		TPA158A4		200		V/V
		TPA158A5		500		V/V
GE	Gain Error	T_A = −40°C to 125°C		±0.15	±0.55	%
	Nonlinearity Error	T_A = −40°C to 125°C, GND + 0.5 V ≤ V_{OUT} ≤ V_S – 0.5 V		±0.05		%
GE TC (1)	Gain Error vs. Temperature	T_A = −40°C to 125°C		±2	±20	ppm/°C
C_{LOAD}	Maximum Capacitive Load	No oscillation		500		pF
V_{OH}	Output Swing from Supply Rail	R_L = 10 kΩ to GND, T_A = −40°C to 125°C		70	150	mV
V_{OL}	Output Swing from Supply Rail	R_L = 10 kΩ to GND, V_{SENSE} = 0 mV, T_A = −40°C to 125°C		5	20	mV
Frequency Response						
BW	Bandwidth	TPA158x1, x2, x3, x4; C_{LOAD} = 5 pF		1000		kHz
		TPA158x5; C_{LOAD} = 5 pF		600		kHz
SR	Slew Rate	V_{SENSE} = V_{IN+} – V_{IN-} = 30 mV		4		V/μs
T_S	Setting Time	V_{OUT} = 4 V ± 0.1-V step, output settles to 1%		5		μs
Power Supply						
V_S	Supply Voltage	T_A = −40°C to 125°C	3.0		20.0	V
I_Q	Quiescent Current	V_S = 3.0 V, T_A = −40°C to 125°C		0.7	1.3	mA

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
		V_S = 12.0 V, T_A = −40°C to 125°C		0.8	1.4	mA
PSRR	Power Supply Rejection Ratio	3.0 V < V_S < 20.0 V, T_A = −40°C to 125°C	100	120		dB

(1) Provided by bench tests and design simulation.
(2) RTI = referred to input.

Typical Performance Characteristics

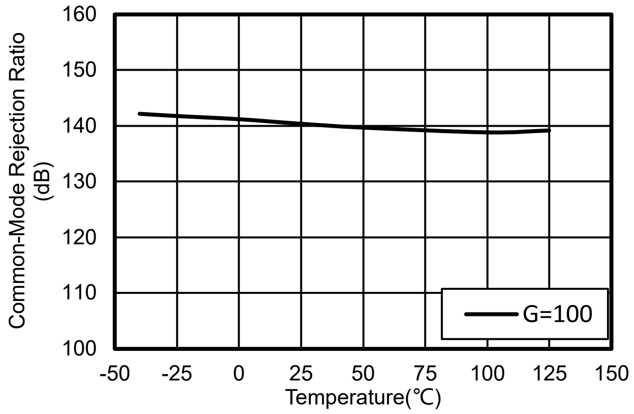


Figure 1. Common-Mode Rejection Ratio vs. Temperature

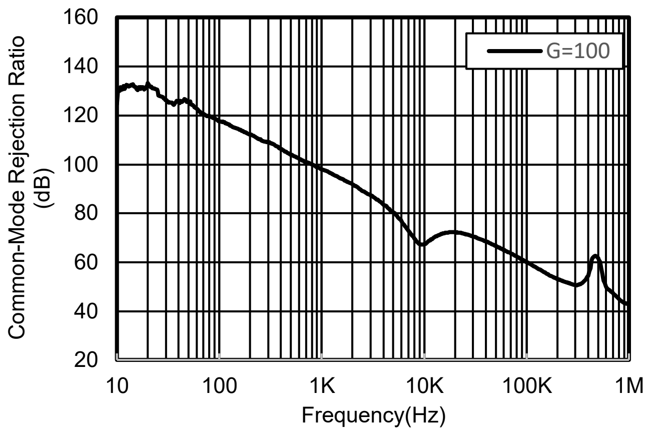


Figure 2. Common-Mode Rejection Ratio vs. Frequency

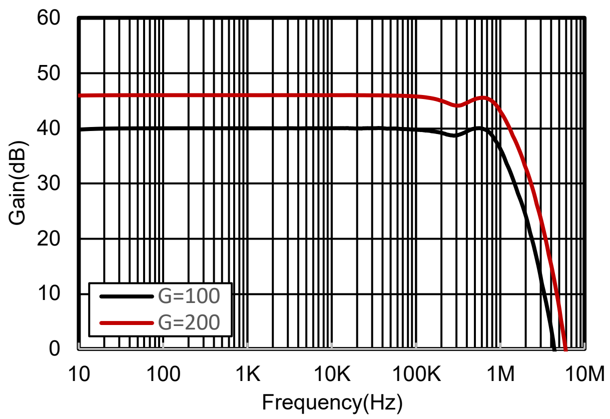


Figure 3. Gain vs. Frequency

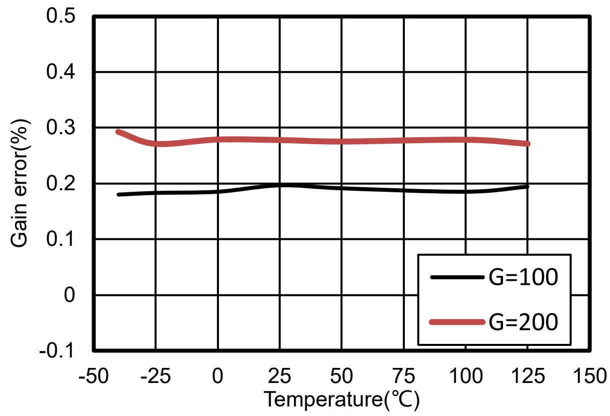


Figure 4. Gain Error vs. Temperature

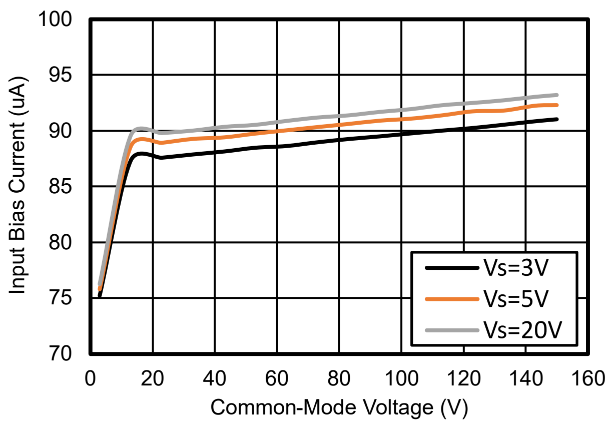


Figure 5. Input Bias Current vs. Common-Mode Voltage

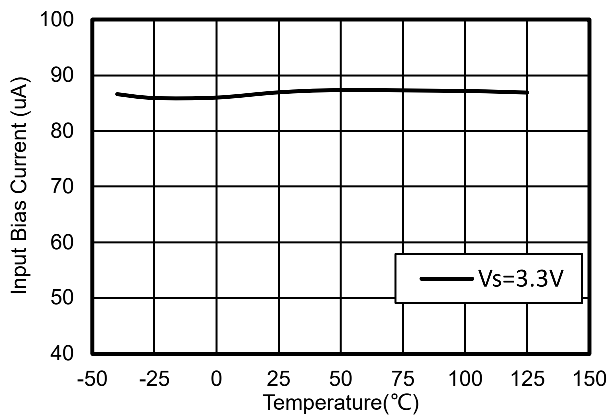


Figure 6. Input Bias Current vs. Temperature

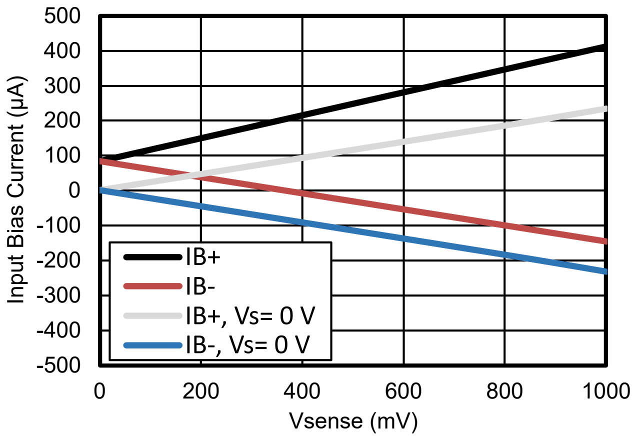


Figure 7. Input Bias Current vs. V_{SENSE}, A3 Devices

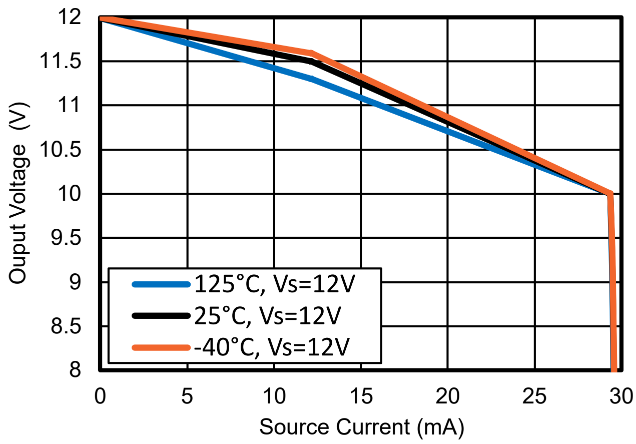


Figure 8. Output Voltage vs. Source Current

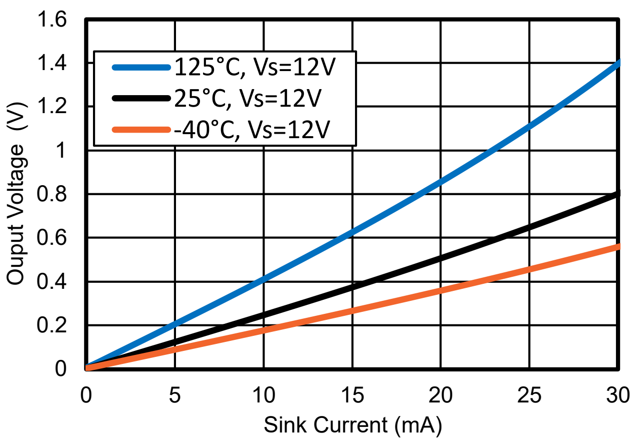


Figure 9. Output Voltage vs. Sink Current

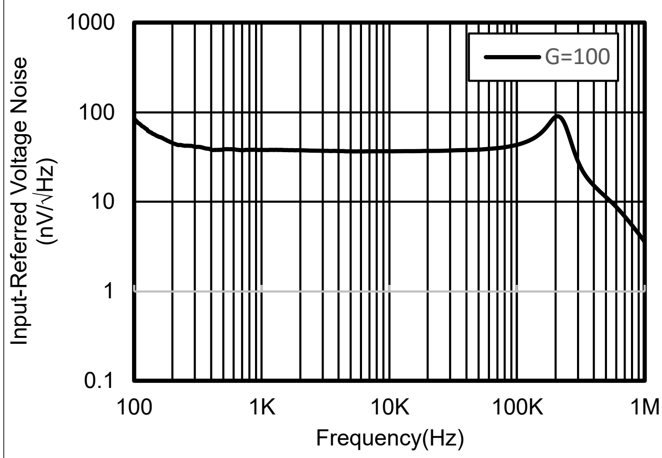


Figure 10. Input Referred Noise vs. Frequency

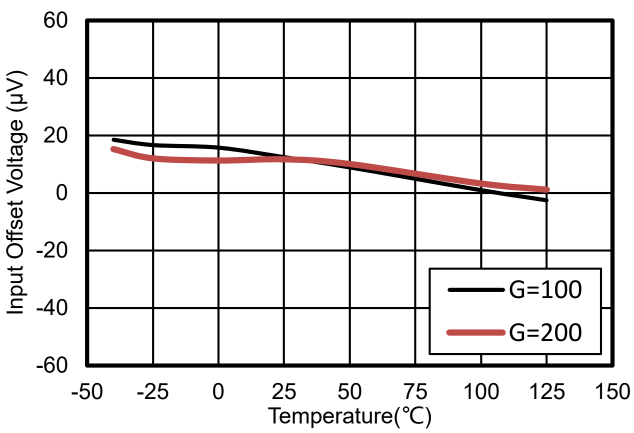


Figure 11. Input Offset Voltage vs. Temperature

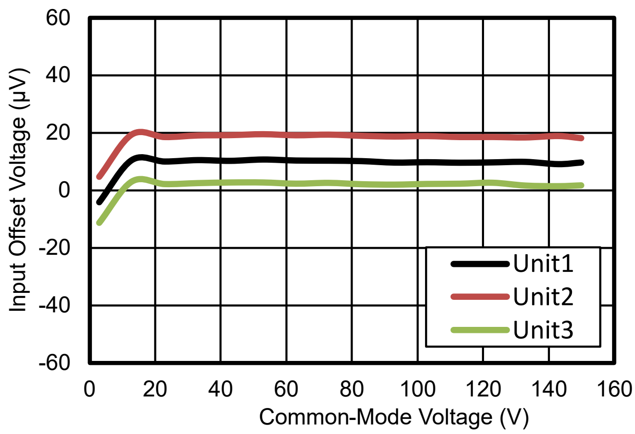


Figure 12. Input Offset Voltage vs. Common-Mode Voltage

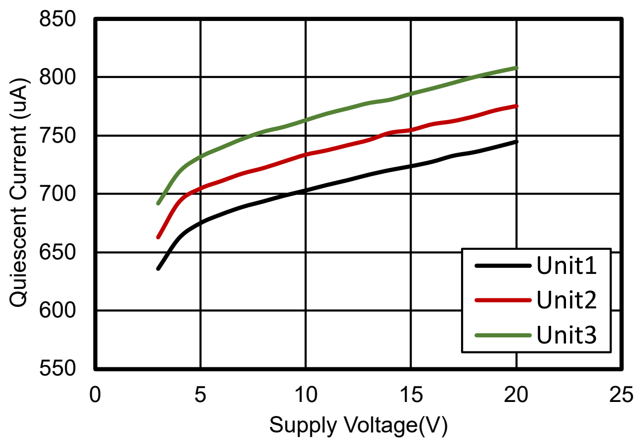


Figure 13. Quiescent Current vs. Supply Voltage

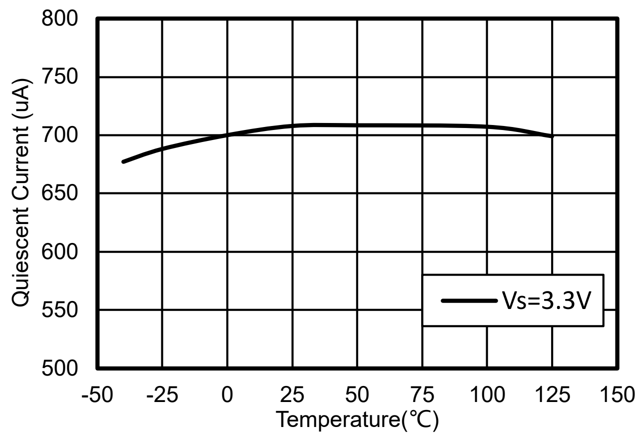


Figure 14. Quiescent Current vs. Temperature

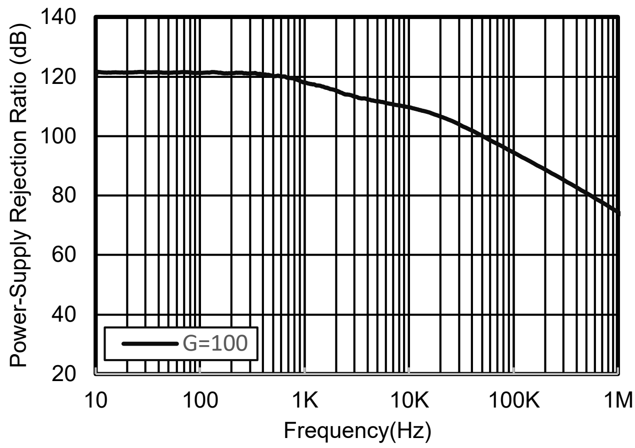


Figure 15. Power Supply Rejection Ratio vs. Frequency

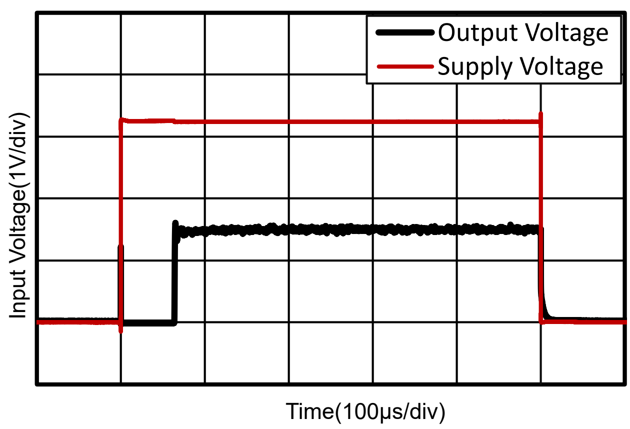


Figure 16. Supply Transient Response

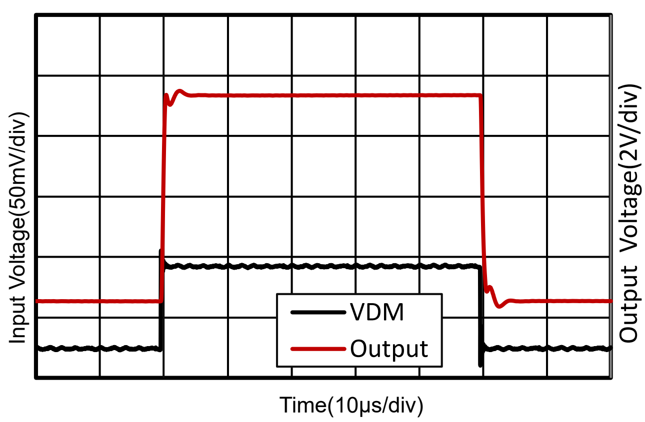


Figure 17. TPA158x3 Large-Signal Response

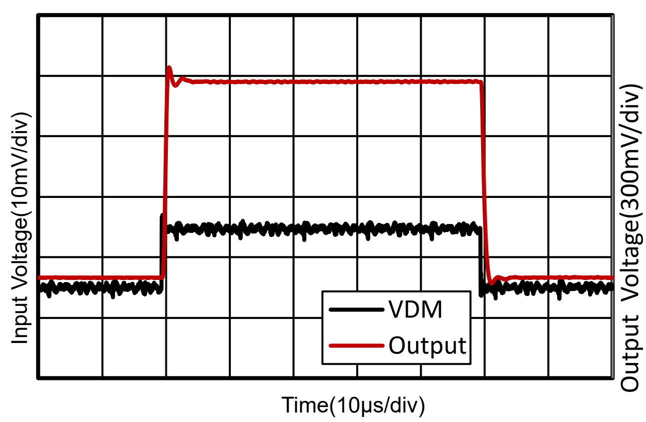


Figure 18. TPA158x3 Small-Signal Response

Detailed Description

Overview

The TPA158 series features a high-accuracy current-sense amplifier in various gain options, and a 3-V to 150-V input common-mode range that is independent of supply voltage (V_S). The low input offset voltage, tight gain error, and low-temperature drift characteristics allow the use of small-sense resistors for current measurements to improve the efficiency of power supply conversion and accuracy of measurements. High-side current monitoring does not interfere with the ground path of the load measured, making the IC particularly useful in a wide range of high-reliability systems.

Functional Block Diagram

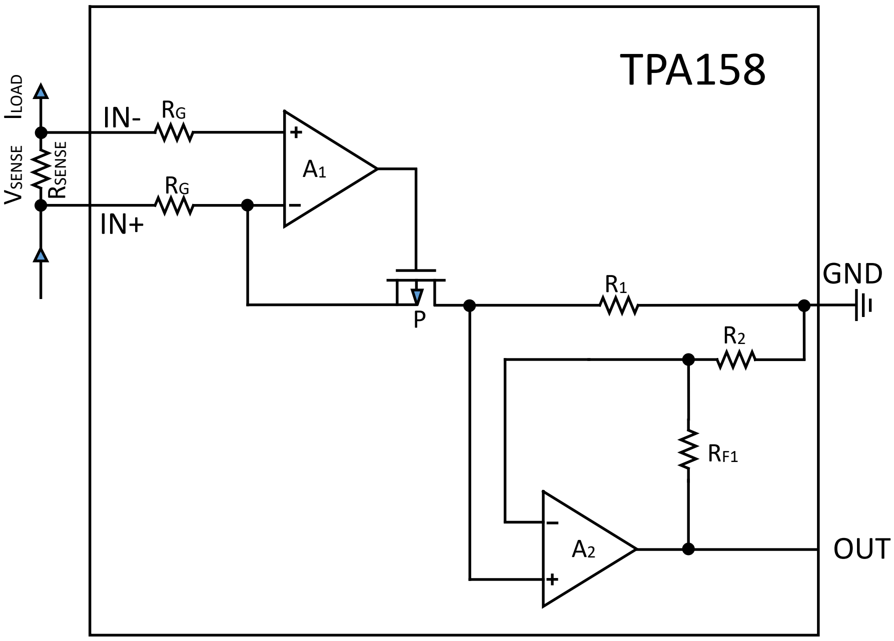


Figure 19. Functional Block Diagram

Feature Description

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:

$$V_{OUT} = V_{SENSE} \times A_V \quad (1)$$

Where V_{SENSE} is the full-scale sense voltage, and A_V is the gain of the TPA158.

In applications of monitoring high currents, ensure that R_{SENSE} is able to dissipate its own I^2R power loss. If the power dissipation of the resistor exceeds the nominal value, its value may drift, or it may fail altogether. The TPA158 senses a wide variety of currents with different sense-resistor values.

Input Filtering

Based on user design requirements, external filtering of the current signal may be desired. The initial location that can be considered for the filter is at the output of the current-sense amplifier. Although placing the filter at the output satisfies the filtering requirements, this location changes the low output impedance measured by any circuitry connected to the output voltage pin. The other location for filter placement is at the input pins of the current-sense amplifier. This location also satisfies the filtering requirements, but the components must be carefully selected to minimize the impact on device performance. Figure 20 shows a filter placed at the input pins.

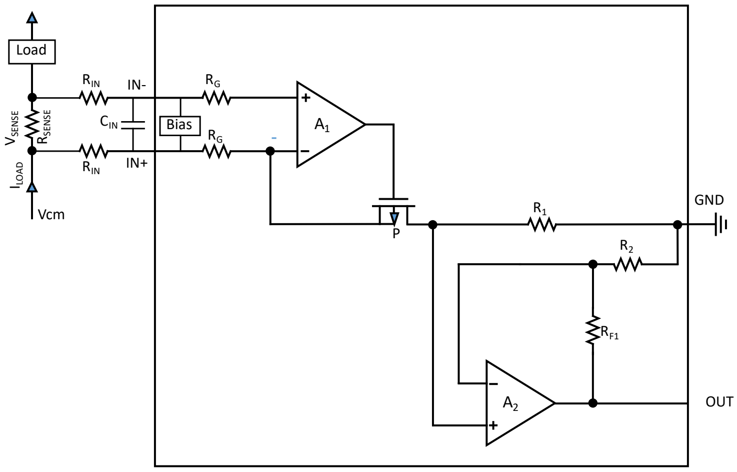


Figure 20. Filter at Input Pins

External series resistance creates additional measurement errors, so the value of these series resistors should be kept to 10 Ω or less to reduce the loss of accuracy. The internal bias network shown in Figure 20 creates a mismatch in input bias currents when the differential voltage is applied between the input pins. If additional external series filter resistors are added to the circuit, a mismatch is created in the voltage drop across the filter resistors. This voltage is a differential error in the shunt resistor voltage. In addition to the absolute resistor value, the mismatch from resistor tolerance can significantly impact the error because this value is calculated based on the actual measured resistance.

The measurement error expected from the additional external filter resistors and the gain error factor are calculated as follows.

$$\text{Gain Error (\%)} = 100 - (100 \times \text{Gain Error Factor}) \quad (2)$$

$$\text{Gain Error Factor} = \frac{R_B \times R_G}{(R_B \times R_G) + (R_B \times R_{IN}) + (2 \times R_{IN} \times R_G)} \quad (3)$$

Where:

R_{IN} is the external filter resistance value;

R_G is the TPA158 input resistance value specified in Table 2;

R_B in the internal bias resistance is 5000 Ω ± 20%.

Table 2. Fixed Gain Resistor

Gain	R_B	R_G	R_1	R_2	R_{F1}
20 (V/V)	5 kΩ	25 kΩ	50 kΩ	20 kΩ	180 kΩ
50 (V/V)	5 kΩ	10 kΩ	50 kΩ	20 kΩ	180 kΩ
100 (V/V)	5 kΩ	10 kΩ	100 kΩ	20 kΩ	180 kΩ
200 (V/V)	5 kΩ	5 kΩ	100 kΩ	20 kΩ	180 kΩ
500 (V/V)	5 kΩ	2 kΩ	100 kΩ	20 kΩ	180 kΩ

Layout

Layout Guideline

- Connect the input pins to the sensing resistor using a Kelvin or 4-wire connection. This connection technique ensures that only the current-sensing resistor impedance is detected between the input pins. Poor routing of the current-sensing resistor commonly results in additional resistance between the input pins. Given the low value of the current resistor, any additional high-current carrying impedance causes significant measurement errors.
- Ensure that the sensing resistor has ample copper trace area for effective heat dissipation. This minimizes temperature-induced changes in the value of the resistor, maintaining measurement accuracy.
- The power-supply bypass capacitor should be placed as close as possible to the supply and ground. The recommended value of this bypass capacitor is 0.1 µF. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies.

Layout Example

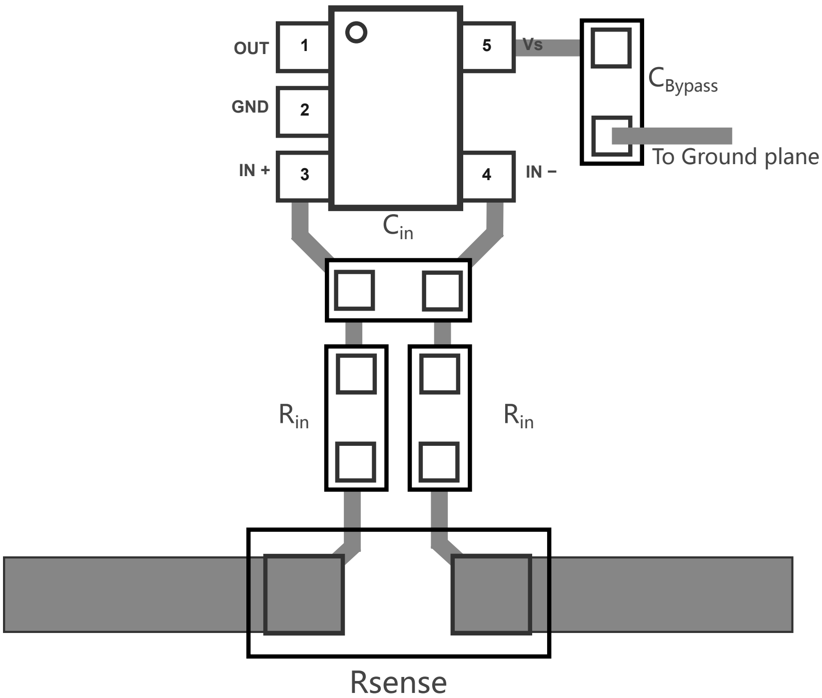


Figure 21. TPA158Ax Recommended Layout

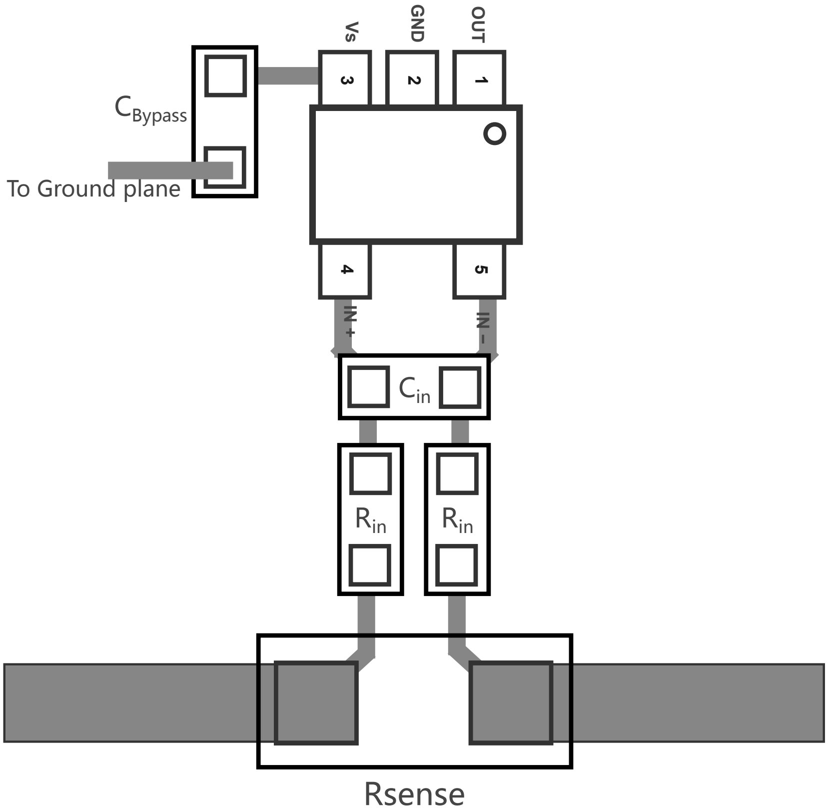
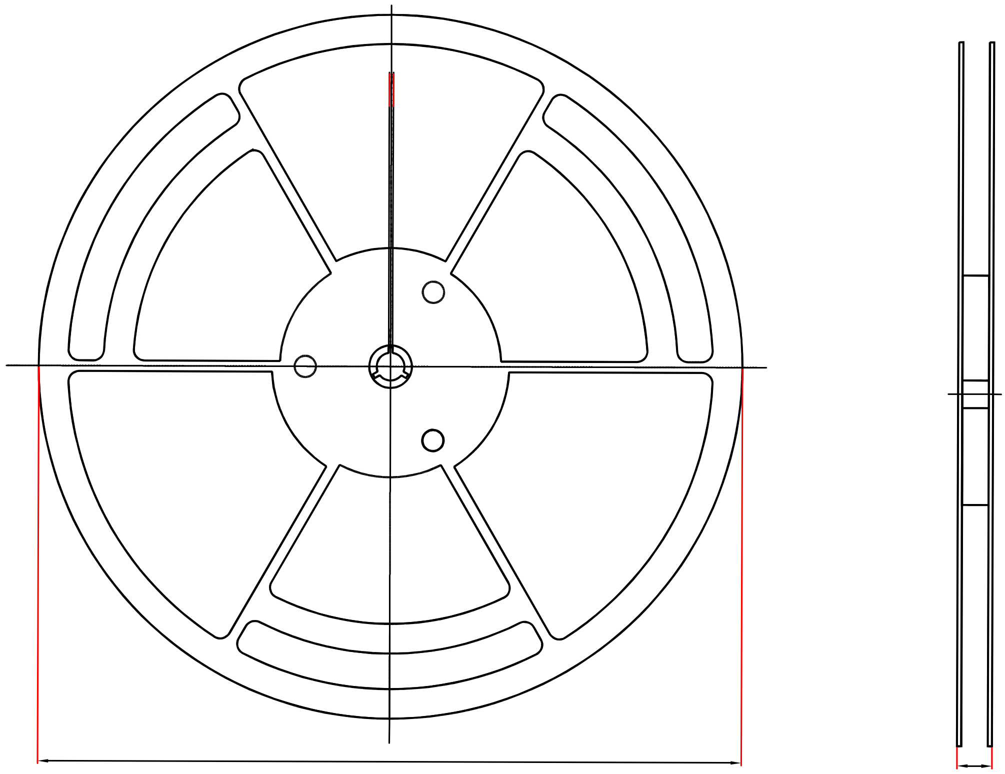
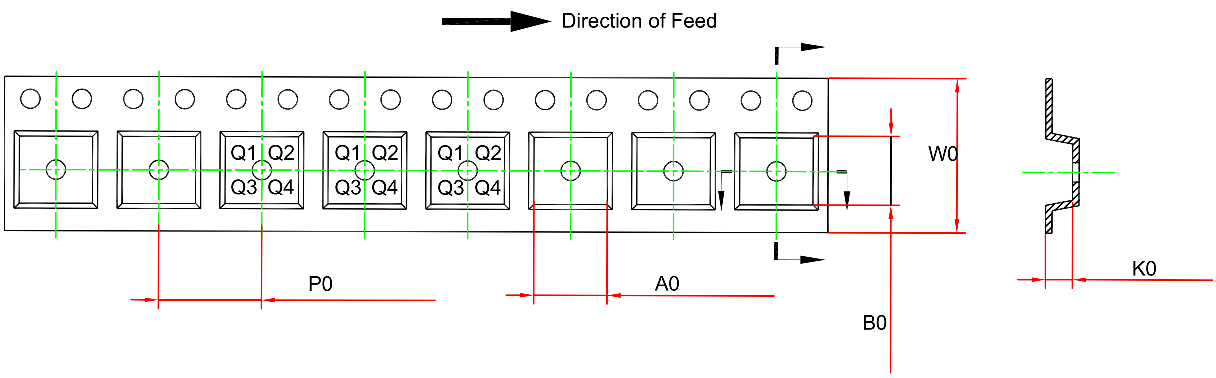


Figure 22. TPA158Bx Recommended Layout

Tape and Reel Information





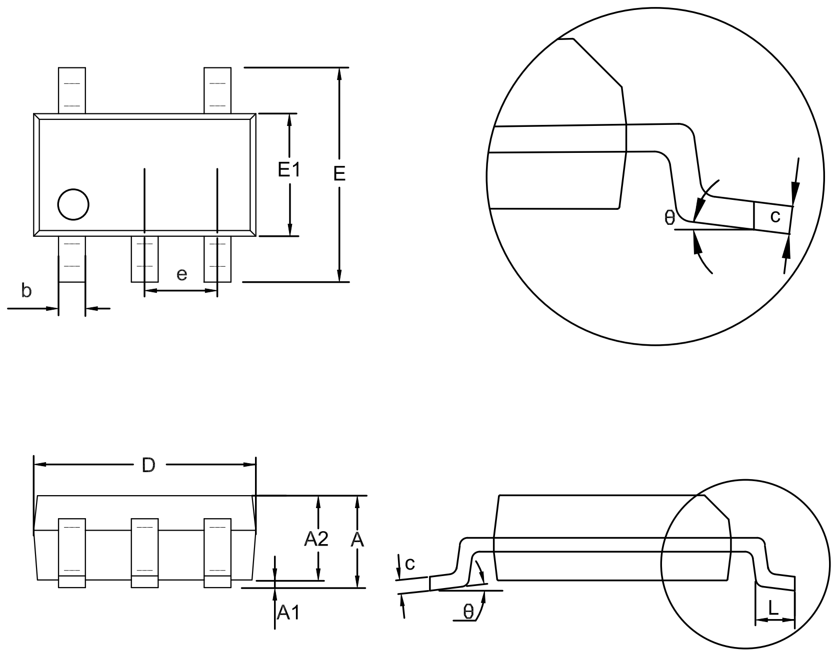
Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm) (1)	B0 (mm) (1)	K0 (mm) (1)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TPA158Ax-S5TR-S	SOT23-5	180.0	12.0	3.3	3.25	1.4	4.0	8.0	Q3
TPA158Bx-S5TR-S	SOT23-5	180.0	12.0	3.3	3.25	1.4	4.0	8.0	Q3

(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	Operating Temperature Range	Package	Marking Information	MSL	Transport Media, Quantity	Eco Plan
TPA158A1-S5TR-S (1)	20 V/V	−40 to 125 °C	SOT23-5	A61	MSL1	Tape and Reel, 3,000	Green
TPA158A2-S5TR-S	50 V/V	−40 to 125 °C	SOT23-5	A62	MSL1	Tape and Reel, 3,000	Green
TPA158A3-S5TR-S	100 V/V	−40 to 125 °C	SOT23-5	A63	MSL1	Tape and Reel, 3,000	Green
TPA158A4-S5TR-S	200 V/V	−40 to 125 °C	SOT23-5	A64	MSL1	Tape and Reel, 3,000	Green
TPA158A5-S5TR-S (1)	500 V/V	−40 to 125 °C	SOT23-5	A65	MSL1	Tape and Reel, 3,000	Green
TPA158B1-S5TR-S (1)	20 V/V	−40 to 125 °C	SOT23-5	A71	MSL1	Tape and Reel, 3,000	Green
TPA158B2-S5TR-S	50 V/V	−40 to 125 °C	SOT23-5	A72	MSL1	Tape and Reel, 3,000	Green
TPA158B3-S5TR-S	100 V/V	−40 to 125 °C	SOT23-5	A73	MSL1	Tape and Reel, 3,000	Green
TPA158B4-S5TR-S	200 V/V	−40 to 125 °C	SOT23-5	A74	MSL1	Tape and Reel, 3,000	Green
TPA158B5-S5TR-S	500 V/V	−40 to 125 °C	SOT23-5	A75	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.

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