Zero-Drift, Bi-Directional Current Sense Amplifier

Features

- Voltage Offset:
  - ±100 µV (Max) at V_{CM} = 2.75 V
  - ±250 µV (Max) at V_{CM} = 12 V
- Wide Common-Mode Voltage: −0.3 V to +36 V
- Supply Voltage: 2.7 V to 36 V
- Accuracy and Zero-Drift Performance
  - ±1% Gain Error (Max over temperature)
  - 0.2 µV/°C Offset Drift (Typ)
  - 10 ppm/°C Gain Drift (Max)
- Three Gain Options for Voltage Output
  - TPA191A1: 20 V/V
  - TPA191A2: 50 V/V
  - TPA191A3: 75 V/V
  - TPA191A4: 100 V/V
  - TPA191A5: 200 V/V
  - TPA191A6: 500 V/V
  - TPA191A7: 1000 V/V
- Low Supply Current: 80 µA (Typ)
- Rail-to-Rail Output
- Package: SOT363
- Industrial −40°C to 125°C Operating Range

Applications

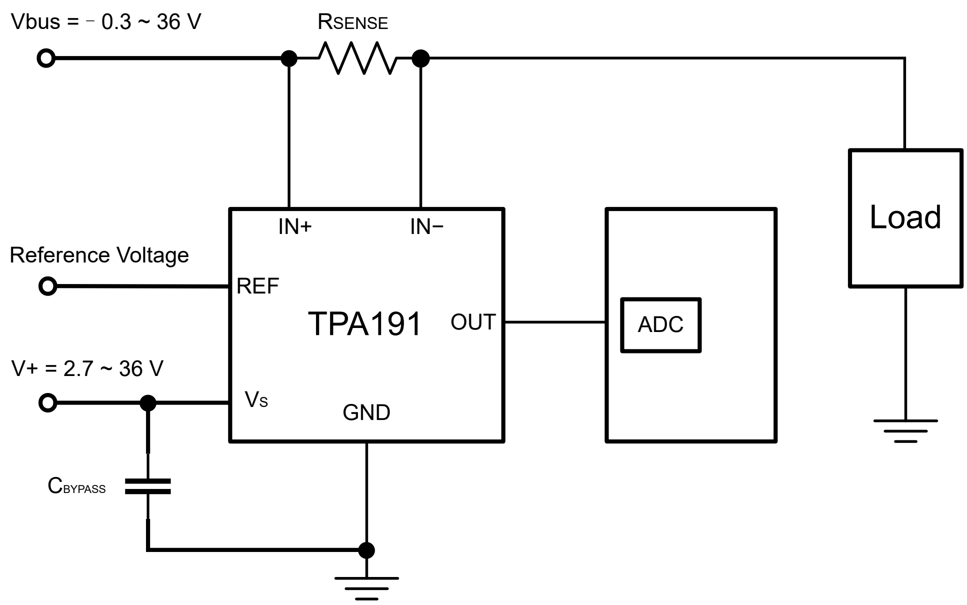
- Current Sensing (High−Side/Low−Side)
- Battery Charger
- Power Management
- Cell Phone Charger
- Electrical Cigarette
- Wireless Charger
- Telecom Equipment

Description

The TPA191 series of zero-drift, bi-directional current sense amplifier can sense voltage drops across shunts at common-mode voltages from −0.3 V to 36 V, independent of the supply voltage. Five fixed gains are available: 20 V/V, 50 V/V, 75 V/V, 100 V/V, and 200 V/V. The integration matched gain resistor network minimizes gain errors and reduces the temperature drift. The low offset of the zero-drift architecture enables current sensing with the maximum drops across the shunt as low as 10-mV full-scale.

The TPA191 devices operate from a single 2.7-V to 36-V power supply, with drawing a typical of 80-µA supply current. All versions are specified from −40°C 125°C, and offered in the SOT363 package.

Typical Application Circuit



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Revision History

Date	Revision	Notes
2023-02-10	Rev.Pre.0	Preliminary version.
2023-03-15	Rev.A.0	Inital release.
2023-03-31	Rev.A.1	Modified the mark information from "9Ax" to "1Ax", "x" represents 1, 2, 3, 4, 5.
2023-04-19	Rev.A.2	Added new part: TPA191A6(G=500), TPA191A7(G=1000). Updated HBM: 2kV -> 3kV based on new test result.
2024-04-27	Rev.A.3	Updated Electrical Characteristics: V_{OS} at V_{IN+} = 12 V, V_{SENSE} = 0 mV: changed Min value from -180 to -250, changed Max value from 180 to 250, added Typ value. V_{OS} at V_{IN+} = 2.75 V, V_{SENSE} = 0 mV: changed Min value from -50 to -100, changed Max value from 50 to 100, added Typ value.

Pin Configuration and Functions

TPA191
SOT363 Package
Top View

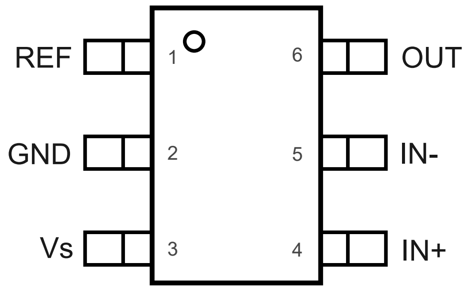


Table 1. Pin Functions: TPA191

Pin No.	Pin Name	I/O	Description
1	REF	I	Reference voltage, 0 V to V_S
2	GND	—	Ground
3	V_S	I	Power supply, 2.7 V to 36 V
4	IN+	I	Noninverting input
5	IN–	I	Inverting input
6	OUT	O	Output

Specifications

Absolute Maximum Ratings (1)

Parameter		Min	Max	Unit
Supply Voltage			42	V
Analog Input, IN+, IN−	Differential (IN+) − (IN−)	−42	42	V
	Common-mode	GND − 0.3	42	V
REF Input		GND − 0.3	V_S + 0.3	V
Output		GND − 0.3	V_S + 0.3	V
Input Current into All Pins (2)		−10	10	mA
Operating Temperature		−40	125	°C
Junction Temperature			150	°C
Storage Temperature, T_{stg}		−65	150	°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.
(2) Input voltage at any pin can exceed the voltage shown if the current at that pin is limited to 10 mA.

ESD, Electrostatic Discharge Protection

Parameter		Condition	Minimum Level	Unit
HBM	Human Body Model ESD	ANSI/ESDA/JEDEC JS-001 (1)	3	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.

Recommended Operating Conditions

Parameter		Min	Typ	Max	Unit
V_S	Operating Supply Voltage	2.7		36	V
V_{CM}	Common-Mode Input Voltage	−0.3		36	V
T_A	Operating Free-Air Temperature	−40		125	°C

Thermal Information

Package Type	θ_{JA}	θ_{JC}	Unit
SOT363	227	80	°C/W

Electrical Characteristics

All test conditions: T_A = 27°C, V_S = 5.5 V, V_{IN+} = 12 V, and V_{SENSE} = V_{IN+} – V_{IN-}, and V_{REF} = V_S / 2, unless otherwise noted.

Parameter		Conditions	Min	Typ	Max	Unit
Supply Voltage and Current						
V_S	Operating Voltage Range	T_A= −40°C to 125°C	2.7		36	V
I_Q	Quiescent Current	V_{SENSE} = 0 mV, T_A = −40°C to 125°C		80	115	μA
Input						
V_{OS}	Input Offset Voltage	V_{SENSE} = 0 mV	−250	±100	250	μV
		V_{IN+} = 2.75 V, V_{SENSE} = 0 mV	−100	±50	100	
V_{OS} TC	Input Offset Voltage Drift	T_A = −40°C to 125°C		0.2		μV/°C
V_{CM}	Common-Mode Input Range	T_A = −40°C to 125°C	−0.3		36	V
CMRR	Common Mode Rejection Ratio	V_{IN+} = 0 V to 26 V, V_{SENSE} = 0 mV, T_A = −40°C to 125°C	95	120		dB
I_B	Input Bias Current	V_{SENSE} = 0 mV		22		μA
I_{OS}	Input Offset Current	V_{SENSE} = 0 mV		±0.05		μA
PSRR	Power Supply Rejection Ratio	V_S = 2.7 V to 18 V, V_{IN+} = 18 V, V_{SENSE} = 0 mV, T_A = −40°C to 125°C	100	128		dB
Output						
G	Gain TPA191A1			20		V/V
	TPA191A2			50		
	TPA191A3			75		
	TPA191A4			100		
	TPA191A5			200		
	TPA191A6			500		
	TPA191A7			1000		
GE	Gain Error	V_{SENSE} = −5 mV to 5 mV, T_A = −40°C to 125°C		±0.05	±1	%
GE TC	Gain Error vs Temperature	T_A= −40°C to 125°C		3	10	ppm/°C
NE	Nonlinearity Error	V_{SENSE} = −5 mV to 5 mV		±0.05		%
C_{LOAD}	Maximum Capacitive Load	No sustained oscillation		1		nF
V_{OH}	Output Swing from Supply Rail	R_L = 10 kΩ to GND, T_A = −40°C to 125°C		0.05	0.11	V
V_{OL}	Output Swing from Supply Rail	R_L = 10 kΩ to GND, T_A = −40°C to 125°C		0.01	0.05	V

Electrical Characteristics (continued)

All test conditions: T_A = 27°C, V_S = 5.5 V, V_{IN+} = 12 V, and V_{SENSE} = V_{IN+} – V_{IN-}, and V_{REF}= V_S / 2, unless otherwise noted.

Parameter			Conditions	Min	Typ	Max	Unit
Frequency Response							
GBW	Bandwidth	TPA191A1	C_{LOAD} = 10 pF		150		kHz
		TPA191A2			80		
		TPA191A3			50		
		TPA191A4			30		
		TPA191A5			15		
		TPA191A6					
		TPA191A7					
SR	Slew Rate		T_A = −40°C to 125°C	1		2.5	V/μs
Noise, RTI							
e_n	Input Voltage Noise Density				35		nV/√Hz
Temperature Range							
	Specified Range			−40		125	°C
	Operating Range			−40		125	°C

Typical Performance Characteristics

All test conditions: T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V, and V_{REF} = V_S / 2, unless otherwise noted.

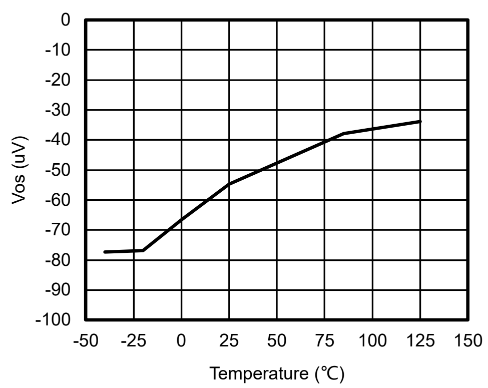


Figure 1. Offset Voltage vs Temperature

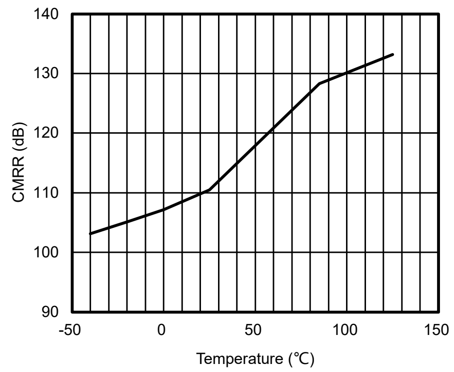


Figure 2. Common-Mode Rejection Ratio vs Temperature

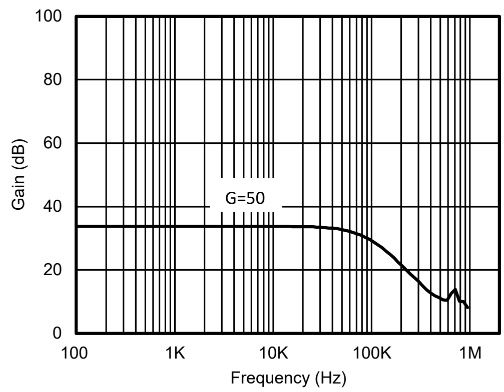


Figure 3. Gain vs Frequency

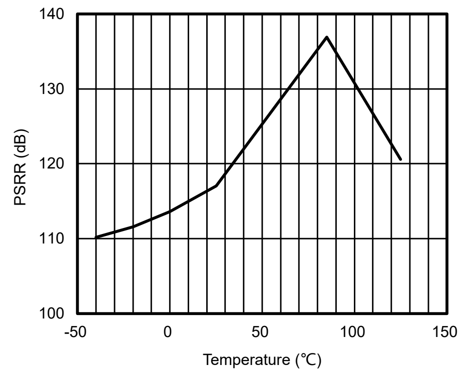


Figure 4. Power-Supply Rejection Ratio vs Temperature

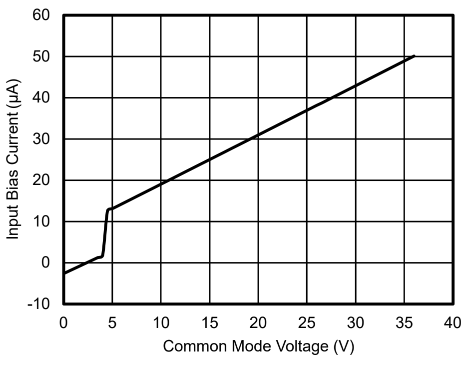


Figure 5. Input Bias Current vs Common-Mode Voltage

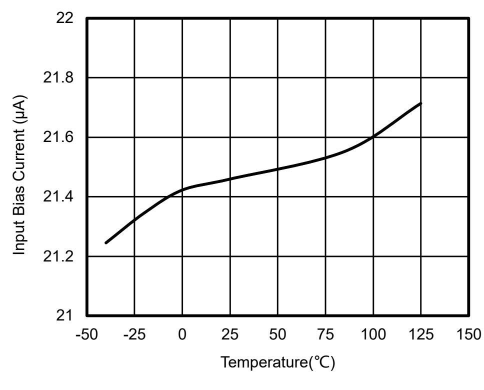


Figure 6. Input Bias Current vs Temperature

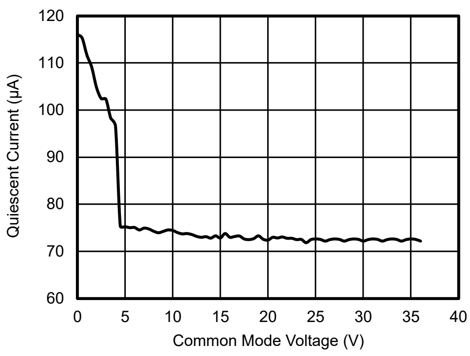


Figure 7. Quiescent Current vs Common-Mode Voltage

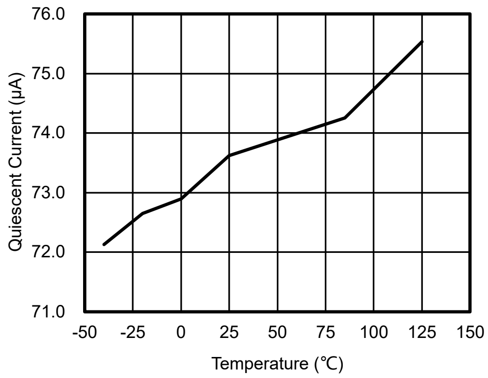


Figure 8. Quiescent Current vs Temperature

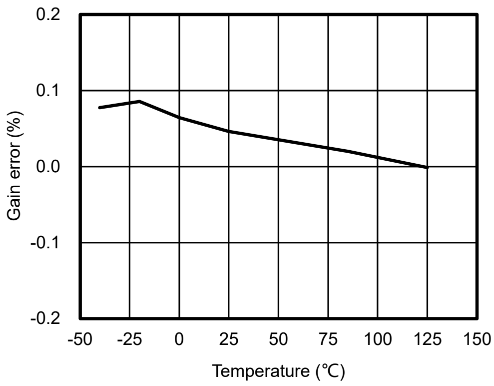


Figure 9. Gain error vs Temperature

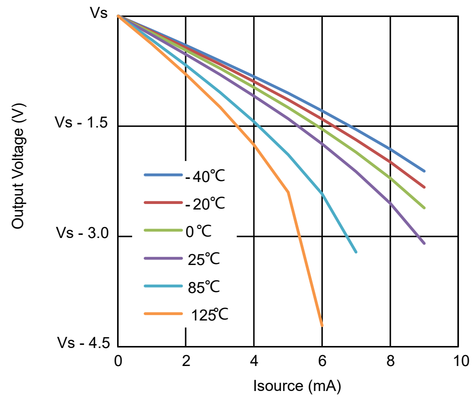


Figure 10. Output Voltage Swing vs I_{source}

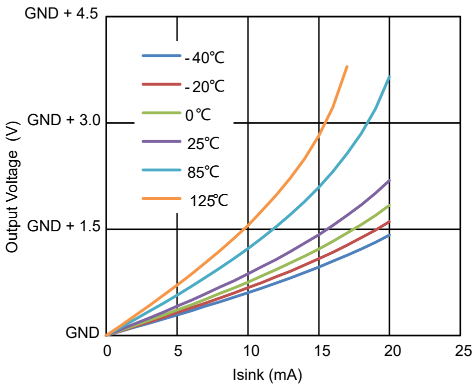


Figure 11. Output Voltage Swing vs I_{sink}

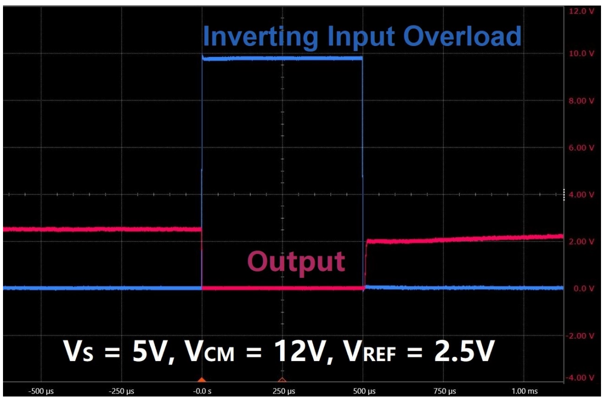


Figure 12. Inverting Differential Input Overload

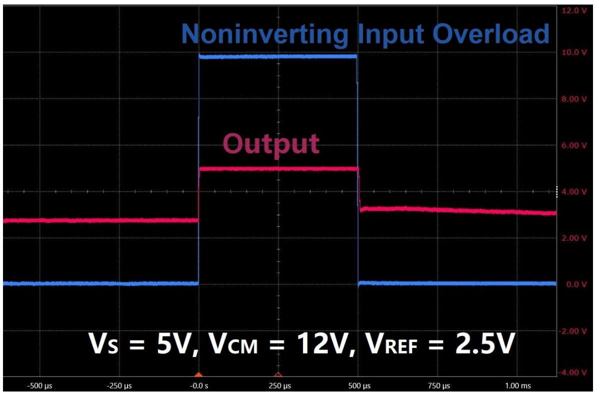


Figure 13. Noninverting Differential Input Overload

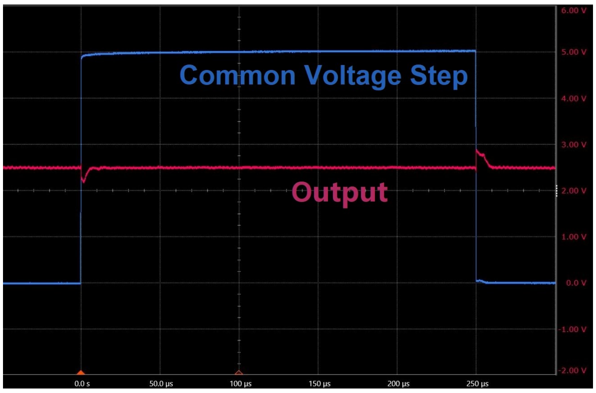


Figure 14. Common-Mode Voltage Transient Response

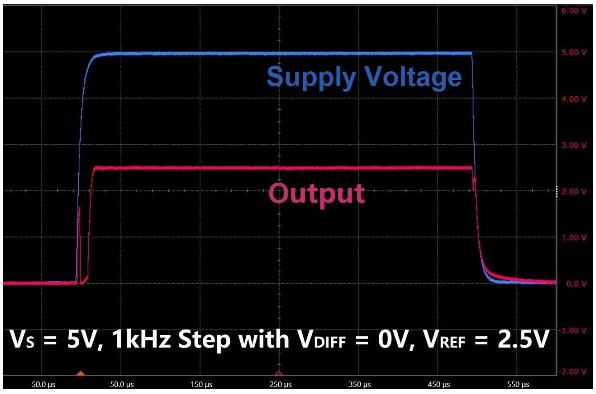


Figure 15. Start-Up Response

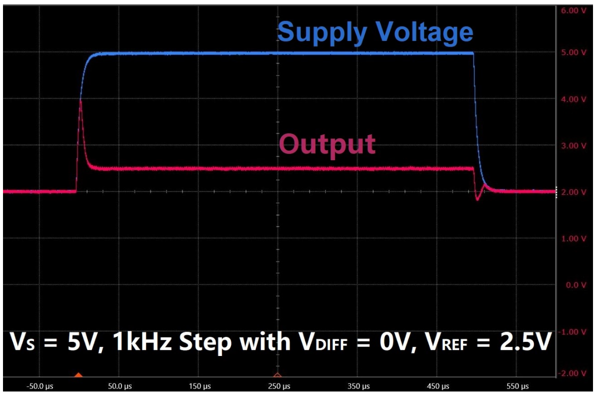


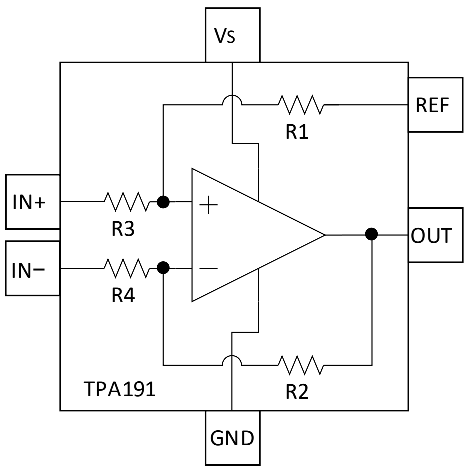
Figure 16. Brownout Recovery

Detailed Description

Overview

The TPA191 family features a high-accuracy unidirectional, current-sense amplifier in various gain options, and a −0.3-V to 36-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 power-supply conversion efficiency and accuracy of measurements. This feature allows monitoring power-supply load current even if the rail is shorted to ground. 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. Because of its extended common-mode range below ground, the TPA191 can also be used as a low-side current sensing element.

Functional Block Diagram



PRODUCT	R1 and R2	R3 and R4
TPA191	1MΩ	1MΩ/GAIN

Figure 17. Functional Block Diagram

Feature Description

Wide Input Common-Mode Voltage Range

Because of the internal topology, the TPA191 supports −0.3 V to 36 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 TPA191 to be used in high-side, as well as low-side current-sensing applications.

Reference Input, REF

The TPA191 supports both unidirectional and bidirectional current-sensing operations. Connecting the reference input (REF) to ground configures the TPA191 for unidirectional current sensing. For unidirectional current sensing, the output is referenced to ground and the output voltage V_{OUT} is proportional to the positive voltage drop (V_{SENSE}) from IN+ to IN-. The TPA191 operates as a bidirectional Current-Sense-Amplifier (CSA) by the application of a low source impedance reference voltage to REF above ground, typically $V_S/2$. In the bidirectional current-sensing mode of operation, the output voltage V_{OUT} is referenced to V_{REF}.

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

The TPA191 monitors the current through a current-sense resistor and amplifes the voltage across the resistor. The 36-V input common-mode voltage range of the TPA191 is independent of the supply voltage. It is a bidirectional, current-sense amplifier capable of measuring currents through a resistive shunt in two directions.

Typical Application

Figure 18 and Figure 19 show the typical application schematics of Unidirectional and Bidirectional applications.

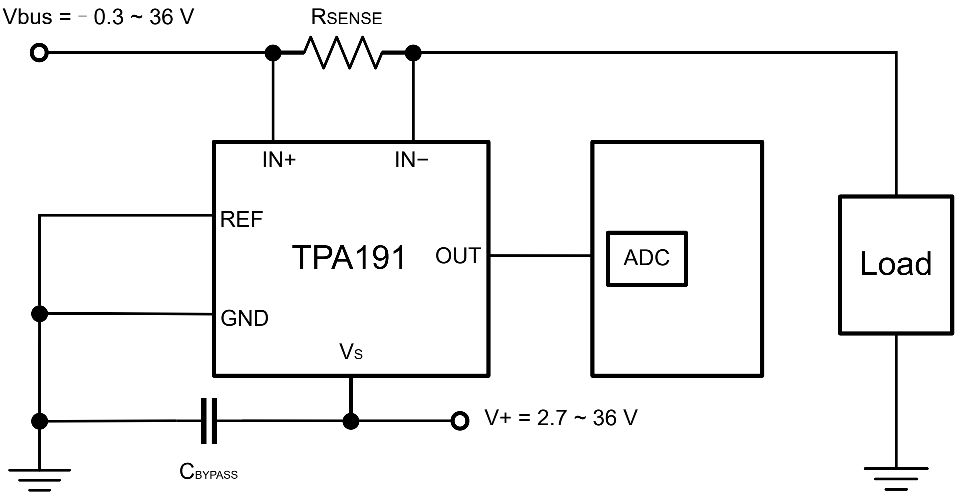


Figure 18. Unidirectional Application Schematic

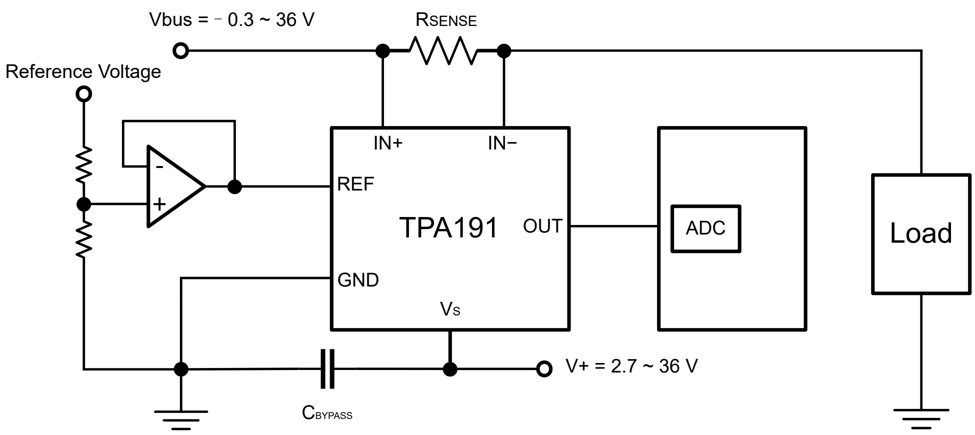


Figure 19. Bidirectional Application Schematic

Bidirectional and Unidirectional Operation

The TPA191 series of products are capable of both unidirectional and bidirectional operations. For unidirectional current-sense applications, connect the REF input to GND. For bidirectional, connect REF to a reference. This sets bidirectional current sense with $V_{OUT} = V_{REF}$ for V_{SENSE} = 0 mV. Positive V_{SENSE} causes OUT to swing toward the positive supply, while negative V_{SENSE} causes OUT to swing toward GND. This feature allows the output voltage to measure both charge and discharge currents. Use $V_{REF} = V_S/2$ for the maximum dynamic range.

Battery-powered systems require a precise bidirectional current-sense amplifier to accurately monitor the battery's charge and discharge currents. Measurements of OUT with respect to V_{REF} yield a positive and negative voltages during charge and discharge cycles.

Choosing the Sense Resistor

A high R_{SENSE} value causes the power-source voltage to drop due to IR loss. For the minimal voltage loss, use the lowest R_{SENSE} value. At high current levels, the I^2R losses in R_{SENSE} can be significant. This should be taken into consideration when choosing the resistor value and its power dissipation (wattage) rating. The sense resistor's value will drift if it is allowed to heat up excessively. A high R_{SENSE} value allows lower currents to be measured more accurately because offsets are less significant when the sense voltage is larger. Note that the tolerance and temperature coefficient of the chosen resistors directly affect the precision of any measurement system. For best performance, select R_{SENSE} to provide approximately the maximum input differential sense voltage with full-scale output voltage for each application. Sense resistors of 5 mΩ to 100 mΩ are available with 1% accuracy or better.

Layout

Layout Guideline

- Because the high currents may flow through R_{SENSE} based on the application, take care to eliminate solder and parasitic trace resistance from causing errors in the sense voltage. Either use a four-terminal current sense resistor or use Kelvin (force and sense) PCB layout techniques.
- Make sure the sense resistor has as much copper trace area as possible to dissipate heat as the resistor value will change slightly with temperature. Also see the resistor manufacturers datasheet or application notes for further layout guidelines.
- The power-supply bypass capacitor should be placed as closely 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 20 shows the location of external components as they appear on the PCB.diagram.

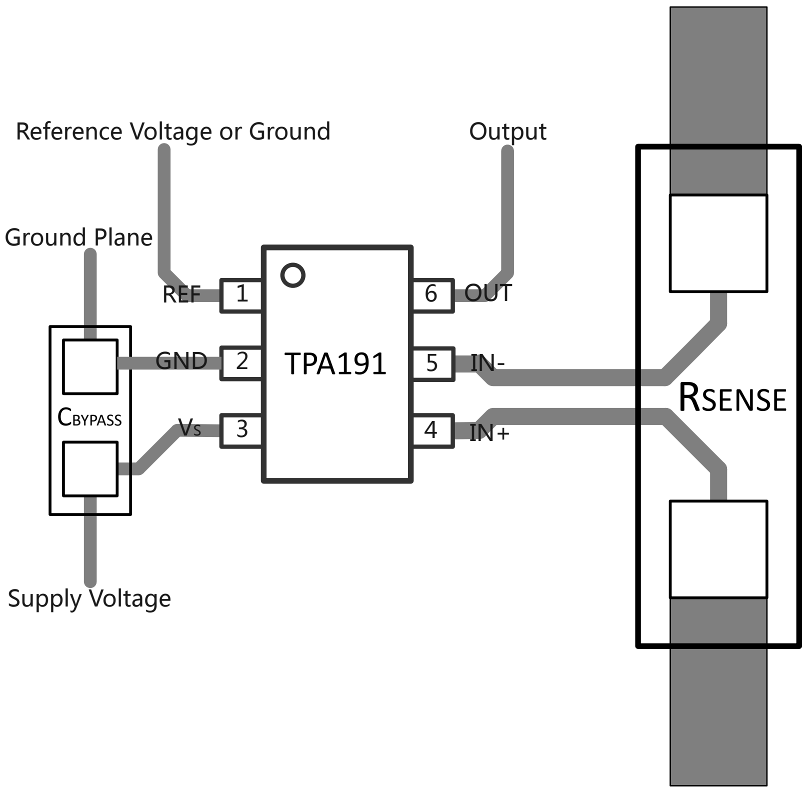
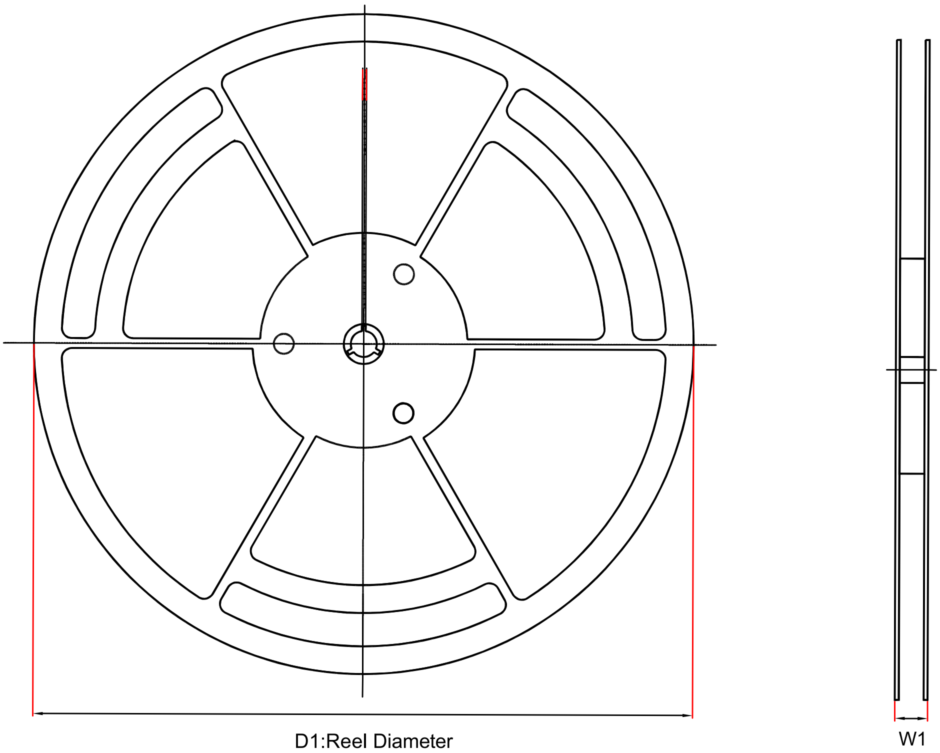
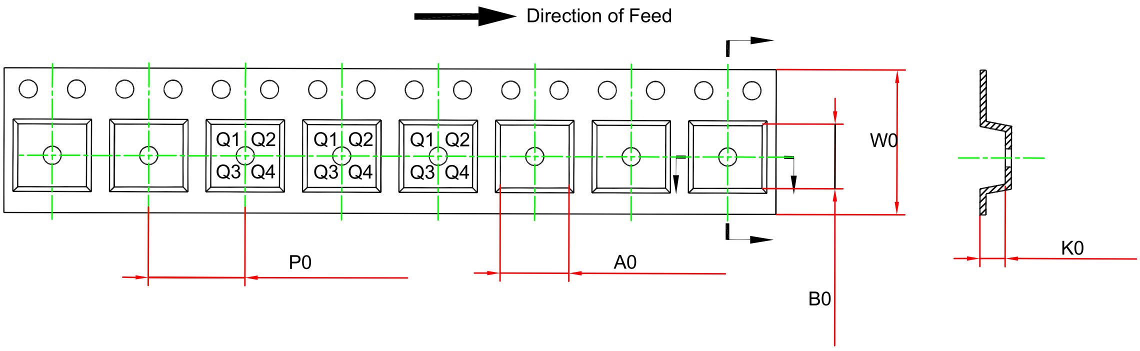


Figure 20. Recommended Layout

Tape and Reel Information



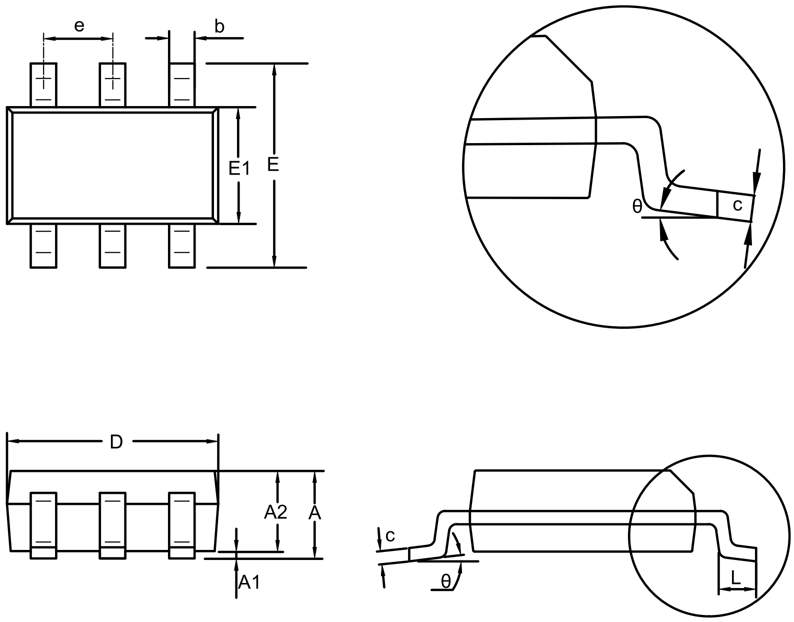


Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TPA191Ax-SC6R	SOT363	178.0	12.1	2.4	2.5	1.2	4.0	8.0	Q3

Package Outline Dimensions

SOT363

Package Outline Dimensions SC6(SOT363-6-A)



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.850	1.100	0.033	0.043
A1	0.000	0.100	0.000	0.004
A2	0.800	1.000	0.031	0.039
b	0.150	0.350	0.006	0.014
c	0.080	0.230	0.003	0.009
D	2.000	2.200	0.079	0.087
E	2.150	2.450	0.085	0.096
E1	1.150	1.350	0.045	0.053
e	0.650 BSC		0.026 BSC	
L	0.260	0.460	0.010	0.018
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 Option	Operating Temperature Range	Package	Marking Information	MSL	Transport Media, Quantity	Eco Plan
TPA191A1-SC6R (1)	20	−40 to 125°C	SOT363	1A1	1	Tape and Reel, 3000	Green
TPA191A2-SC6R	50	−40 to 125°C	SOT363	1A2	1	Tape and Reel, 3000	Green
TPA191A3-SC6R (1)	75	−40 to 125°C	SOT363	1A3	1	Tape and Reel, 3000	Green
TPA191A4-SC6R	100	−40 to 125°C	SOT363	1A4	1	Tape and Reel, 3000	Green
TPA191A5-SC6R	200	−40 to 125°C	SOT363	1A5	1	Tape and Reel, 3000	Green
TPA191A6-SC6R(1)	500	−40 to 125°C	SOT363	1A6	1	Tape and Reel, 3000	Green
TPA191A7-SC6R(1)	1000	−40 to 125°C	SOT363	1A7	1	Tape and Reel, 3000	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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