INA791x –4V to 110V, Bidirectional, Ultra-Precise, High Bandwidth Current Sense Amplifier With 75A EZShunt™ Technology

1 Features

- Precision solution with integrated shunt resistor
  - ±75A continuous current at 25°C
  - ±50A continuous current from –40°C to +125°C
  - Shunt resistor: 400μΩ
  - Shunt inductance: 2nH
- Wide common-mode voltage range: –4V to +110V
- High small signal bandwidth : 1MHz
- Excellent CMRR
  - 160dB DC CMRR
  - 104dB AC CMRR at 100kHz
- High measurement accuracy
  - System Gain error (maximum)
    - Version A: ±0.35%, ±35ppm/°C drift
    - Version B: ±1%, ±75ppm/°C drift
  - Offset current (maximum)
    - Version A: ±30mA, ±625μA/°C drift
    - Version B: ±375mA, ±1.25mA/°C drift
- Adjustable gain with external resistor divider network:
  - 20mV/A to 400mV/A
- Open-drain temperature alert at T_J of 160°C
- Package options: VQFN-15

2 Applications

- 48V DC/DC Converter
- 48V battery management systems (BMS)
- Test & Measurement
- Macro remote radio unit (RRU)
- 48V rack server
- 48V merchant network & server power supply (PSU)

3 Description

The INA791x is a voltage output, current sense amplifier with an integrated shunt resistor of 400μΩ. The INA791x is designed to monitor bidirectional current over a common-mode range of –4V to 110V, independent of the supply voltage. Adjustable gain option assists in optimizing the system dynamic range. The integration of the Kelvin connected shunt resistor with a zero-drift chopped amplifier provides calibration equivalent measurement accuracy, ultra-low temperature drift performance of 35ppm/°C, and an optimized layout for the sensing resistor.

This device operates from a single 2.7V to 5.5V power supply, drawing a maximum of 3.75mA of supply current. All versions are specified over the extended operating temperature range (–40°C to +125°C), and are available in a 15-pin VQFN package.

Package Information

PART NUMBER	PACKAGE(1)	PACKAGE SIZE(2)
INA791A, INA791B	DEK (VQFN, 15)	6mm × 6mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.
(2) The package size (length × width) is a nominal value and includes pins, where applicable.

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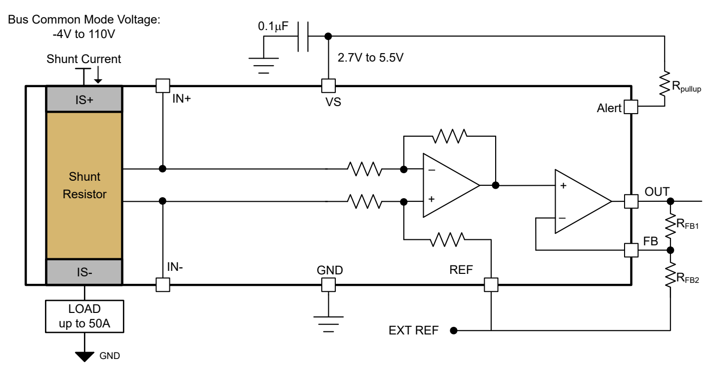

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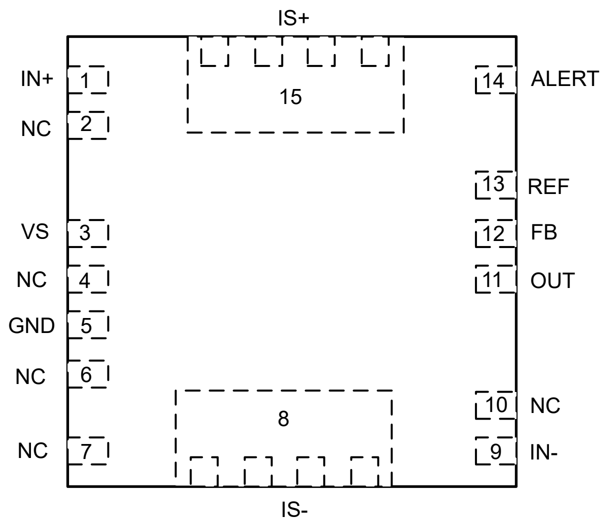

Figure 4-1. INA791x DEK Package 15-Pin VQFN Top View

Table 4-1. Pin Functions

PIN		Type	DESCRIPTION
NAME	NO.		
ALERT	14	Digital Out	Open-drain temperature alert
FB	12	Analog Input	Gain adjustment feedback; connect to resistor divider to adjust device gain
GND	5	Analog	Ground
IN–	9	Analog Input	Kelvin connection to internal shunt on load side and negative amplifier input
IN+	1	Analog Input	Kelvin connection to internal shunt on supply side and positive amplifier input
IS–	8	Analog Input	Connect to load
IS+	15	Analog Input	Connect to supply
NC	2	–	Connect to IN+ (Pin 1)
NC	4, 6, 7	–	Connect to ground or leave unconnected
NC	10	–	Connect to IN– (Pin 9)
OUT	11	Analog Output	Output voltage
REF	13	Analog Input	Reference voltage, 0V to VS
VS	3	Analog	Power supply, 2.7V to 5.5V

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5 Specifications

5.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1]

		MIN	MAX	UNIT
Supply voltage (V_S)			6	V
Analog Inputs, V_{IN+}, V_{IN-} [2]	Differential (V_{IN+}) - (V_{IN-})	–12	12	V
	Common-mode	GND – 20	120	V
Analog input (REF)	Analog input (REF)	GND – 0.3	Vs + 0.3	V
Analog input (FB)	Analog input (FB)	GND – 0.3	Vs + 0.3	V
Analog output (OUT)	Analog output (OUT)	GND – 0.3	Vs + 0.3	V
Digital output (ALERT)	Temperature Alert Output	GND – 0.3	Vs + 0.3	V
T_A	Operating Temperature	–55	150	°C
T_J	Junction temperature		150	°C
T_{stg}	Storage temperature	–65	150	°C

(1) Operation outside the Absolute Maximum Ratings may cause permanent device damage. Absolute Maximum Ratings do not imply functional operation of the device at these or any other conditions beyond those listed under Recommended Operating Conditions. If used outside the Recommended Operating Conditions but within the Absolute Maximum Ratings, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.

(2) V_{IN+} and V_{IN-} are the voltages at the IN+ and IN– pins, respectively.

5.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins[1]	±2000	V
		Charged device model (CDM), per ANSI/ESDA/JEDEC JS-002, all pins[2]	±1000	

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

5.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
V_{CM}	Common-mode input range	–4		110	V
V_S	Operating supply range	2.7		5.5	V
I_{SENSE}	Continuous Current	–50		50	A
V_{REF}	Reference voltage range	0		V_S	V
V_{FB}	Feed-back voltage range	0		V_S	V
T_A	Ambient temperature	–40		125	°C

5.4 Thermal Information

THERMAL METRIC[1]		INA791x DEK (VQFN) 15 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	28.7	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	8.3	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance[2]	30.8	°C/W
Ψ_{JT}	Junction-to-top characterization parameter[2]	1.1	°C/W

THERMAL METRIC[1]		INA791x DEK (VQFN) 15 PINS	UNIT
Ψ_{JB}	Junction-to-board characterization parameter[2]	8.4	°C/W

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application note.
(2) Thermal metrics are relative to the internal die and are conservative relative to the heating that occur from the package leadframe shunt. For more details on heating, see the Safe Operating Area section.

5.5 Electrical Characteristics

at T_A = 25°C, V_S = 5V, I_{SENSE} = IS+ = 0A, V_{CM} = 48V, V_{FB} = V_{OUT}, and V_{REF} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	V_{IN+} = –4V to 110V, I_{SENSE} = 0A, T_A = –40°C to +125°C	–4		110	V
CMRR	Common-mode rejection ratio	V_{IN+} = –4V to 110V, I_{SENSE} = 0A, T_A = –40°C to +125°C, INA791A		±25	±79	µA/V
		V_{IN+} = –4V to 110V, I_{SENSE} = 0A, T_A = –40°C to +125°C, INA791B		±790	±2500	
CMRR	Common-mode rejection ratio	f = 50kHz		±56		mA/V
I_{os}	Offset current, input referred	I_{SENSE} = 0A, INA791A		±5	±30	mA
		I_{SENSE} = 0A, INA791B		±62.5	±375	
dI_{os}/dT	Offset current drift	I_{SENSE} = 0A, T_A = –40°C to +125°C, INA791A		0.125	±0.625	mA/°C
		I_{SENSE} = 0A, T_A = –40°C to +125°C, INA791B		0.250	±1.25	
PSRR	Power supply rejection ratio	V_S = 2.7V to 5.5V, V_{REF} = 1V, I_{SENSE} = 0A, INA791A		0.25	±2.5	mA/V
		V_S = 2.7V to 5.5V, V_{REF} = 1V, I_{SENSE} = 0A, INA791B		2.5	±25	
I_B	Total input bias current	I_{B+}+ I_{B-}, I_{SENSE} = 0A	±50	±80	±100	µA
I_{FB}	Feed-back current	I_{SENSE} = 0A		±1.3		nA
		I_{SENSE} = 0A, T_A = –40°C to +125°C			±5	
INTEGRATED SHUNT RESISTOR						
R_{SHUNT}	Internal Kelvin shunt resistance	IN+ to IN-, T_A = 25°C	350	400	500	µΩ
	Pin to pin package resistance	IS+ to IS-, T_A = 25°C	450	560	650	µΩ
	Pin to pin package inductance	IS+ to IS-, T_A = 25°C		2		nH
I_{SENSE}	Maximum Continuous Current	T_A = –40°C to +125°C			±50	A
	Short time overload change	I_{SENSE} = 120A for 5 seconds		± 0.05		%
	Change due to temperature cycle	–65°C to 150°C, 500 cycles		± 0.1		%
	Shunt resistance change to solder heat	260°C solder, 10 seconds		± 0.1		%
	High temperature exposure change	1000 hours, T_A = 150°C		± 0.15		%
OUTPUT						
G	Gain	INA791A , INA791B ,		20		mV/A
G	System Gain error (shunt + amplifier) [1]	GND + 50mV ≤ V_{OUT} ≤ V_S – 200mV, T_A = 25°C, INA791A		±0.05	±0.35	%
		GND + 50mV ≤ V_{OUT} ≤ V_S – 200mV, T_A = 25°C, INA791B		±0.1	±1	
G	System Gain error (shunt + amplifier)	T_A = –40°C to +125°C, INA791A		±0.5	±35	ppm/°C
		T_A = –40°C to +125°C, INA791B		±10	±75	

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at T_A = 25°C, V_S = 5V, I_{SENSE} = IS+ = 0A, V_{CM} = 48V, V_{FB} = V_{OUT}, and V_{REF} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
	Non-Linearity Error	GND + 10mV ≤ V_{OUT} ≤ V_S – 200mV		±0.01		%
RVRR	Reference voltage rejection ratio (input - referred)			±2.5	±12.5	mA/V
	Maximum capacitive load	No sustained oscillation		0.5		nF
VOLTAGE OUTPUT						
	Swing to Vs Power Supply Rail	R_L = 10kΩ to GND, V_{REF} = V_S, Adjustable Gain = 4, T_A = –40°C to +125°C		V_S – 0.05	V_S – 0.2	V
	Swing to Ground	R_L = 10kΩ to GND, Adjustable Gain = 4, V_{REF} = GND, T_A = –40°C to +125°C		V_{GND} + 5	V_{GND} + 20	mV
	Swing to Ground	R_L = 10kΩ to GND, V_{REF} = GND, T_A = –40°C to +125°C		V_{GND} + 1	V_{GND} + 5	mV
FREQUENCY RESPONSE						
BW	Bandwidth (current sense amplifier)	–3dB Bandwidth, V_{FB} = V_{OUT}		1		MHz
		–3dB Bandwidth, Adjustable Gain = 4		0.5		MHz
	Settling time (current sense amplifier input to out)	V_{IN+}, V_{IN-} = 48V, V_{OUT} = 1.5V to 3.5V, Output settles to 1%		1.5		µs
		V_{IN+}, V_{IN-} = 48V, Adjustable Gain = 4, V_{OUT} = 0.5V to 4.5V, Output settles to 1%		2.5		µs
		V_{IN+}, V_{IN-} = 48V, V_{OUT} = 1.5V to 3.5V, Output settles to 5%		1		µs
		V_{IN+}, V_{IN-} = 48V, Adjustable Gain = 4, V_{OUT} = 0.5V to 4.5V, Output settles to 5%		2		µs
SR	Slew Rate	V_{FB} = V_{OUT}		1.8		V/µs
		Adjustable Gain = 4		1.5		V/µs
NOISE						
	Current Noise Density			150		µA/√Hz
POWER SUPPLY						
I_Q	Quiescent current			3.5	3.75	mA
		T_A = –40°C to +125°C			4	mA
TEMPERATURE						
Alert	Thermal Alert Threshold	R_{pullup} = 10kΩ,		160		°C
$Alert_{LO}$	Thermal Alert Threshold Swing to Ground	R_{pullup} = 10kΩ,		200		mV

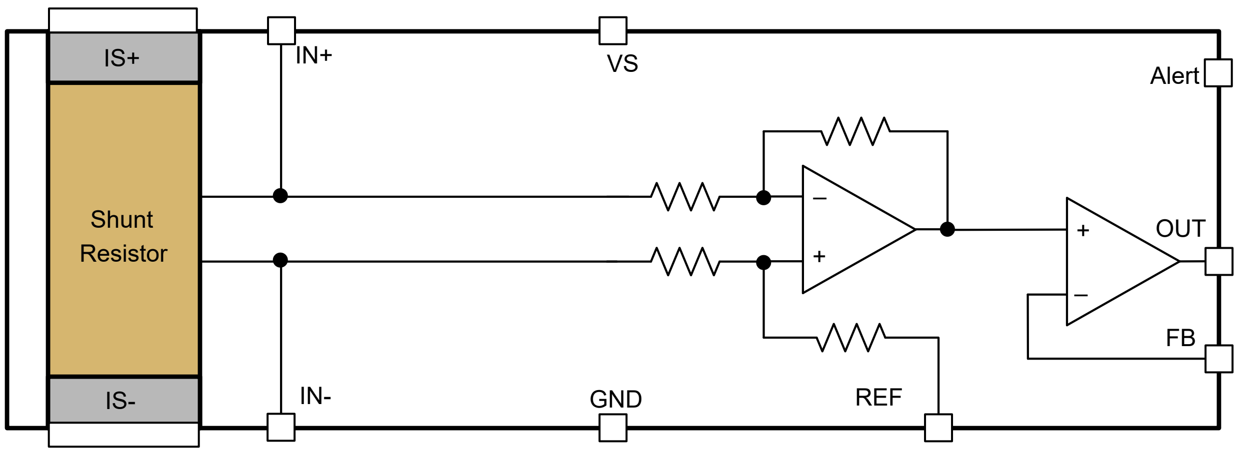
(1) I_{SENSE} = ± 50A, V_{OUT} = V_{REF} ± 1V

6 Detailed Description

6.1 Overview

The INA791x features a precision current sensing solution with 400µΩ current-sensing EZShunt™ technology resistor and supports common-mode voltages up to 110V. The internal amplifier features a precision zero-drift topology with excellent common-mode rejection ratio (CMRR). High-precision measurements are enabled by matching the shunt resistor value and the current-sensing amplifier gain across temperature, thus providing a highly-accurate, system-calibrated method for measuring current. The high-speed current-sensing amplifier helps output settle fast after the common-mode transients. Flexibility of adjustable gain with two external resistors allows for the optimization of the desired full-scale output voltage based on the target current range expected in the application.

6.2 Functional Block Diagram



6.3 Feature Description

6.3.1 Integrated Shunt Resistor

The INA791x features an integrated EZShunt™ technology current-sensing resistor that provides accurate measurements over the entire specified temperature range of –40°C to +125°C. The integrated current-sensing resistor provides measurement stability over temperature, and simplifies printed circuit board (PCB) layout and board constraint difficulties common in high-precision measurements.

The onboard current-sensing resistor is designed as a 4-wire (or Kelvin) connected resistor that enables accurate measurements through a force-sense connection. Internally connected amplifier input pins (IN– and IN+) to the sense pins of the shunt resistor eliminates many instances of parasitic impedance commonly found in typical very-low sensing-resistor level measurements. The INA791x is system-calibrated to make sure that the current-sensing resistor and current-sensing amplifier are both precisely matched to one another. The in-package integrated sensing resistor must be used with the internal current-sensing amplifier to achieve the optimized system gain specification.

The INA791x has approximately 550µΩ of package resistance. Of this total package resistance, 400µΩ resistance from the Kelvin-connected current-sensing resistor is used by the amplifier. The power dissipation requirements of the system and package are based on the total 550µΩ package resistance between the IS+ and IS– pins.

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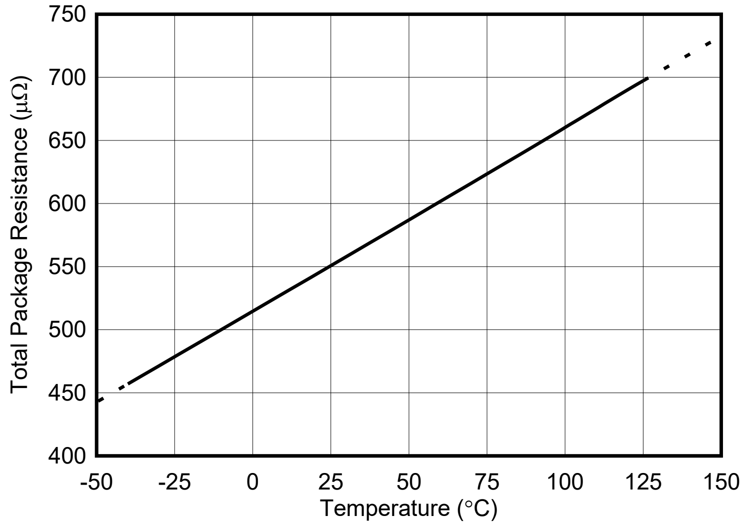

Figure 6-1. IS+ to IS– Package Resistance vs Temperature

6.3.2 Safe Operating Area

The heat dissipated across the package when current flows through the device ultimately determines the maximum current that can be safely handled by the package. The current consumption of the silicon is relatively low, leaving the total package resistance to carry the high load current as the primary contributor to the total power dissipation of the package. The maximum safe-operating current level shown in Figure 6-2 is set to make sure that the heat dissipated across the package is limited so that no damage occurs to the resistor or the package, or that the internal junction temperature of the silicon does not exceed a 165°C limit.

External factors, such as ambient temperature, external air flow, and PCB layout, contribute to how effectively the device dissipates heat. The internal heat is developed as a result of the current flowing through the total package resistance of 550µΩ.

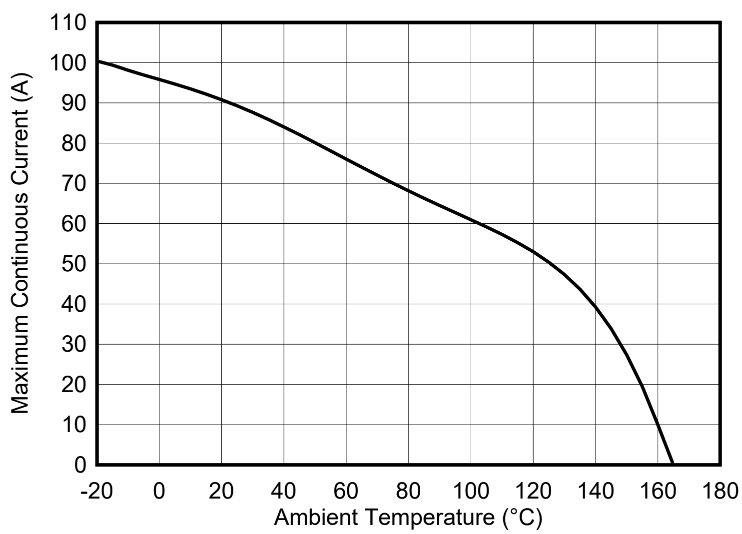

Figure 6-2. Maximum Continuous Current vs Ambient Temperature

6.3.3 Short-Circuit Duration

The INA791x features a physical shunt resistance that is able to withstand current levels higher than the continuous handling limit of 50A without sustaining damage to the current-sensing resistor or the current-sensing amplifier, if the excursions are brief. Figure 6-3 shows the short-circuit duration curve for the INA791x.

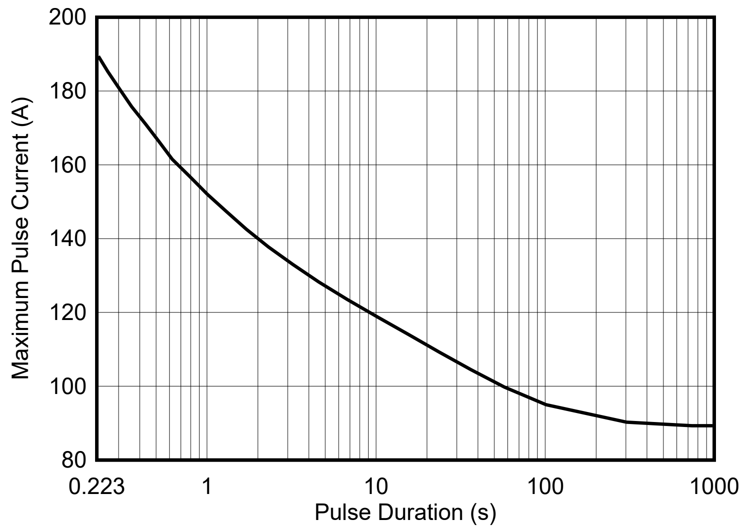

Figure 6-3. Maximum Pulse Current vs Pulse Duration (Single Event)

6.3.4 Temperature Stability

System calibration is common for many industrial applications to eliminate initial component and system-level errors that can be present. A system-level calibration reduces the initial accuracy requirement for many of the individual components because the errors associated with these components are effectively eliminated through the calibration procedure. This calibration enables precise measurements at the temperature in which the system is calibrated. As the system temperature changes because of external ambient changes or self heating, measurement errors are reintroduced. Without accurate temperature compensation used in addition to the initial adjustment, the calibration procedure is not effective. The user must account for temperature-induced changes. The built-in programmed temperature compensation in the INA791x (including both the integrated current-sensing resistor and current-sensing amplifier) keep the device measurement accurate, even when the temperature changes throughout the specified temperature range of the device.

6.4 Device Functional Modes

6.4.1 Adjusting the Output With the Reference Pin

The INA791x output is configurable to allow for unidirectional or bidirectional operation. Figure 6-4 shows a circuit for setting output with an external reference.

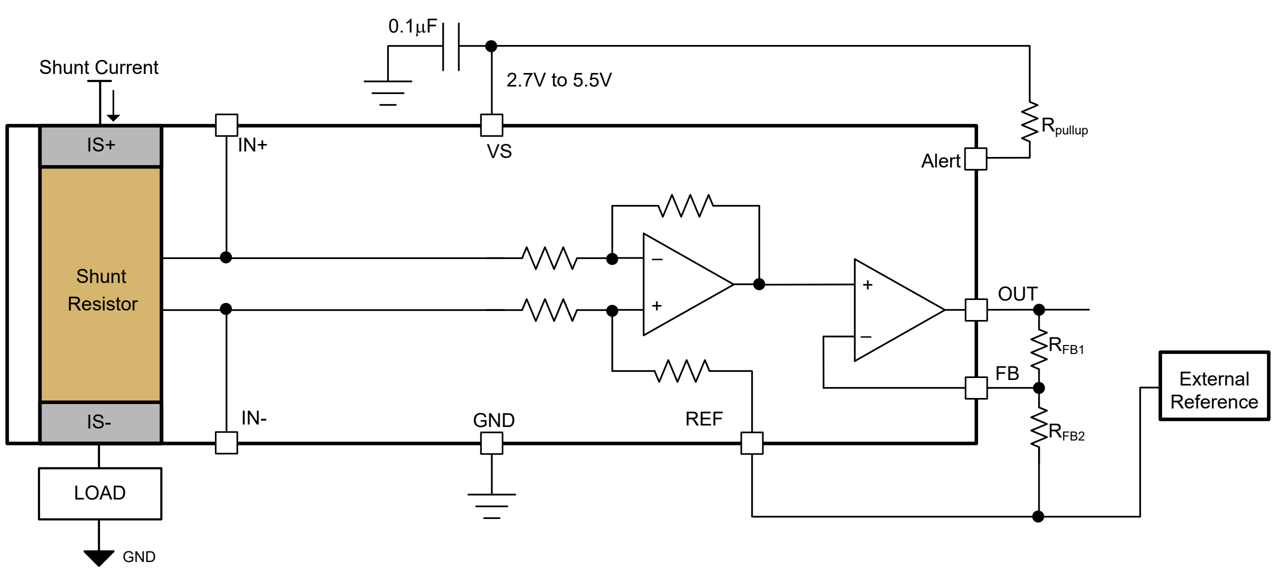

Figure 6-4. Adjusting the Output

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The output voltage is set by applying a voltage from an external reference at REF. The reference input is connected to internal gain network. The external resistor network of R_{FB1} and R_{FB2}, connected to OUT, FB and REF pins, set up adjustable gain as explained in *Adjustable Gain Set Using External Resistors*. Output is set accurately at the voltage provided by external reference as shown in Equation 1 when the resistor R_{FB2} is connected to the same voltage as REF pin. The voltage at REF pin can range between supply Vs and GND. For symmetric bidirectional current sensing REF is set at mid-supply which sets out at mid-supply as well.

$$V_{OUT} = G \times (I_{SHUNT}) + V_{REF} \quad (1)$$

6.4.1.1 Reference Pin Connections for Unidirectional Current Measurements

Unidirectional operation allows current measurements through a resistive shunt in one direction. For unidirectional operation, connect the device reference pin to the negative rail (see the *Ground Referenced Output* section) or positive rail, V_S. The required differential input polarity depends on the output voltage setting. The amplifier output moves away from the referenced rail proportional to the current passing through the internal shunt resistor.

6.4.1.2 Ground Referenced Output

When using the INA791x in unidirectional mode with a ground-referenced output, both REF input and resistor R_{FB2} are connected to ground. Figure 6-5 shows how this configuration takes the output to ground when there is 0A flowing across the internal shunt.

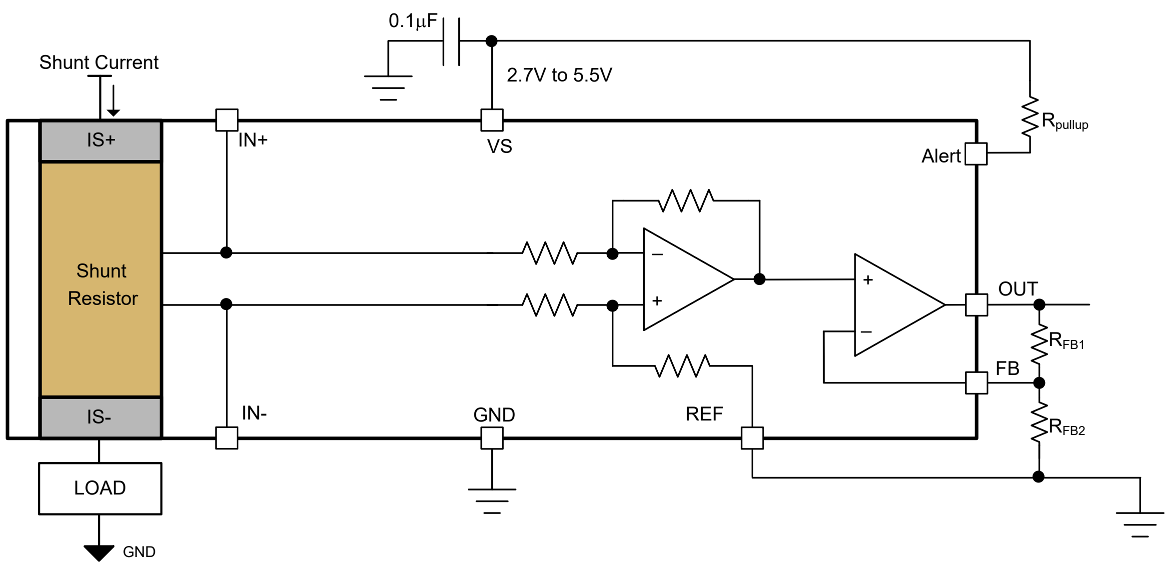

Figure 6-5. Ground-Referenced Output

6.4.1.3 Reference Pin Connections for Bidirectional Current Measurements

Bidirectional operation allows the INA791x to measure currents through a resistive shunt in two directions. For this case, set the output voltage anywhere within the reference input limits. A common configuration is to set the reference inputs at half-scale for equal range in both directions. However, the reference input can be set to a voltage other than half-scale when the bidirectional current is nonsymmetrical.

6.4.1.4 Output Set to Mid-Supply Voltage

Figure 6-6 shows two equal resistors R_1 and R_2 connected between VS and the GND pins divide the supply at half, and by connecting REF pin to the divided supply, output is set to mid-supply voltage. The mid-point of these resistors is buffered using external operational amplifier to avoid loading of resistors resulting in error. The output is set to middle of the supply when there is no differential input voltage or 0A current in shunt resistor. This method creates a ratiometric offset to the supply voltage, where the output voltage remains at VS / 2 when 0A of current flows through internal shunt resistor.

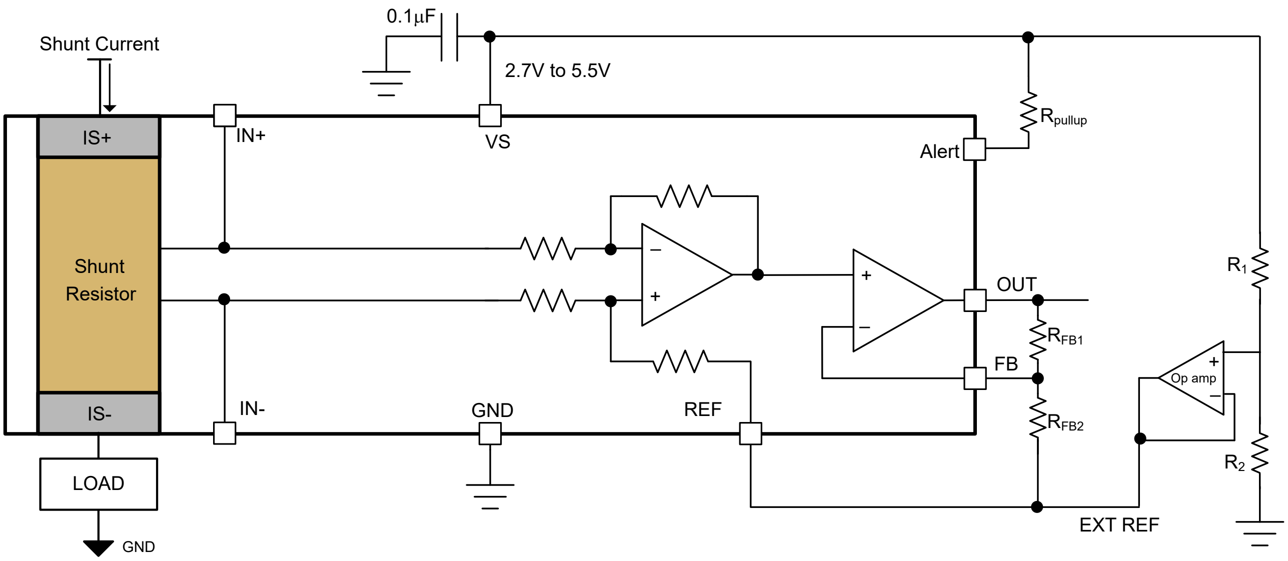

Figure 6-6. Mid-Supply Voltage Output

6.4.2 Adjustable Gain Set Using External Resistors

The INA791x features adjustable gain with two external resistor network. The default gain is 20mV/A, and with added external adjustable gain resistor network, total gain (G) can range up to 400mV/A. Figure 6-7 shows two external resistors R_{FB1} and R_{FB2} configured for added external gain. Equation 2 can be used for calculating external adjustable gain and Equation 3 shows the total gain of the system with external adjustable gain. The REF pin and one end of resistor R_{FB2} is connected to external reference based on needed voltage at OUT pin as described in *Adjusting the Output With the Reference Pin*.

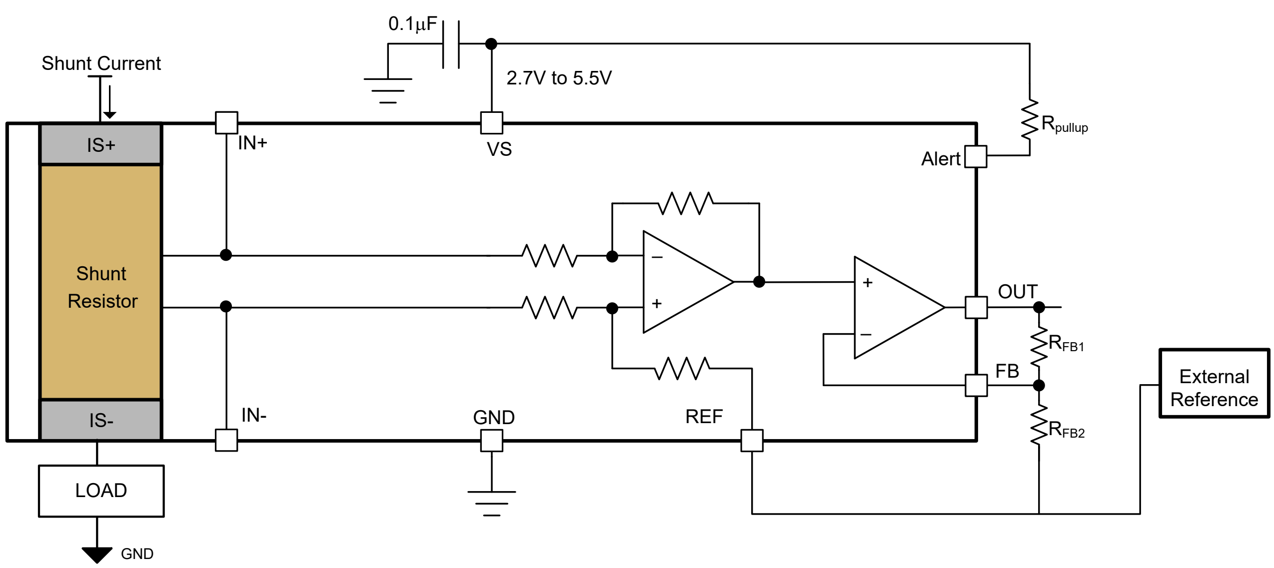

Figure 6-7. Adjustable Gain Setting With External Resistor Divider

$$\text{Adjustable Gain} = \left(1 + \frac{R_{FB1}}{R_{FB2}}\right) \quad (2)$$

$$G = 20\frac{mA}{V} \times \left(1 + \frac{R_{FB1}}{R_{FB2}}\right) \quad (3)$$

The FB pin in INA791x has associated bias current, which can add to error when large values of adjustable gain resistor, R_{FB1}, is used. Alternatively, very low values of adjustable gain resistors load the output of the sense amplifier limiting the capability of the sense amplifier to get close to the supply rail. Keeping the sum of external resistors R_{FB1} and R_{FB2} between 10kΩ and 40kΩ is recommended when external adjustable gain is higher than 1. Table 6-1 shows recommended values of external gain resistors for the most common gains.

Table 6-1. Recommended Values of External Resistors Setting Adjustable Gain

External Adjustable Gain	R_{FB1}	R_{FB2}	Total Gain (G)
1	0Ω (short)	Open	20mV/A
2	20kΩ	20kΩ	40mV/A
4	30kΩ	10kΩ	80mV/A
5	20kΩ	5kΩ	100mV/A

6.4.2.1 Adjustable Unity Gain

Figure 6-8 shows adjustable gain set to unity gain or 1. In this configuration OUT is connected to FB without any external resistor. This unity gain sets INA791x to default minimum gain of 20mV/A. Equation 3 can be used to calculate the total gain of the system. The REF pin is connected to external reference based on needed output voltage setting as described in *Adjusting the Output With the Reference Pin*.

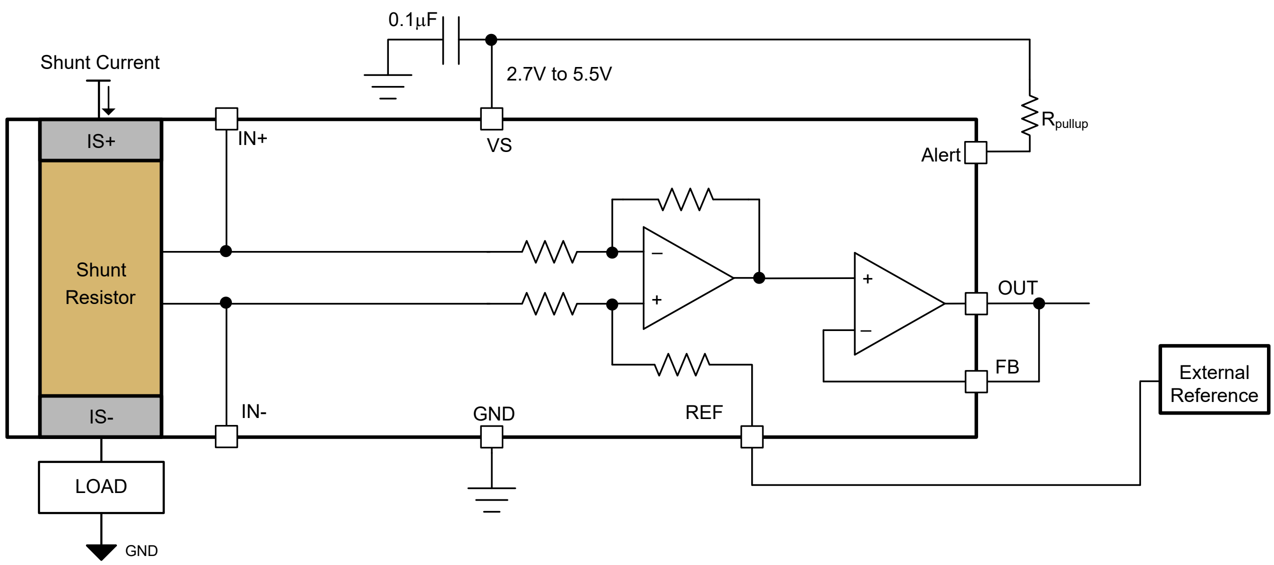

Figure 6-8. Adjustable Unity Gain Setting

6.4.3 Thermal Alert Function

The INA791x has thermal Alert function that provides an alert when internal shunt temperature reaches 160°C. The power dissipation as a result of internal shunt current causes the temperature to rise inside the package. Extended time at temperature higher than 150°C can cause permanent shift in device specification. Thermal alert function can be used to keep the temperature of INA791x below 150°C. Figure 6-9 shows a circuit where R_{pullup} resistor is tied between open-drain Alert pin and the supply pin. When temperature of the INA791x reaches 160°C, the open-drain FET pulls Alert pin to the ground asserting thermal alert.

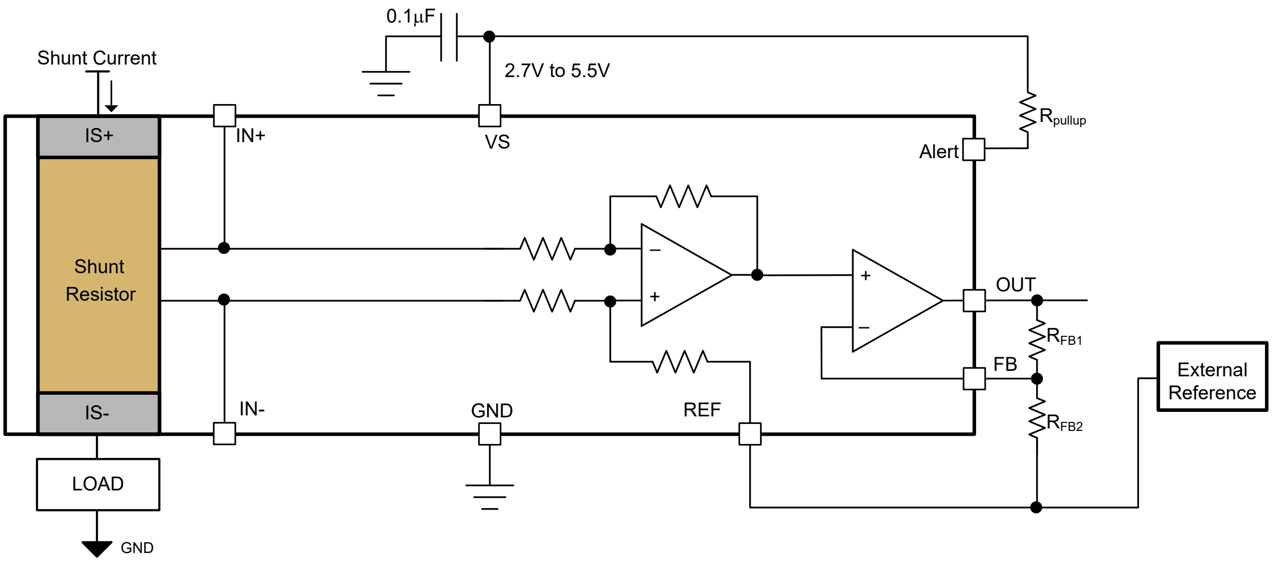

Figure 6-9. Thermal Alert Function

7 Application and Implementation

Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

7.1 Application Information

The INA791x measures the voltage developed as current flows across the integrated current shunt. The device provides a reference pin to configure operation as either unidirectional or bidirectional output swing. When using the INA791x for inline motor current sense or measuring current in an H-bridge, the device is commonly configured for bidirectional operation.

7.1.1 Calculating Total Error

The INA791x electrical specifications *Electrical Characteristics* include typical individual errors terms (such as gain error, offset error, and nonlinearity error). Total error, including all of these individual error components, is not specified in the table. To accurately calculate the expected error of the device, the user must first know the device operating conditions. This section discusses the individual error sources and how the device total error value can be calculated from the combination of these errors for specific conditions.

Three examples are provided in Table 7-1, Table 7-2, and Table 7-3 that detail how different operating conditions can affect the total error calculations. Typical and maximum calculations are shown as well to provide the user more information on how much error variance is present from device to device.

7.1.1.1 Error Sources

The typical error sources that have the largest effect on the total error of the device are gain error, nonlinearity, common-mode rejection ratio, and input offset error. For the INA791x, an additional error source (referred to as the *reference voltage rejection ratio*) is also included in the total error value.

7.1.1.2 Reference Voltage Rejection Ratio Error

Reference voltage rejection ratio refers to the amount of error induced by applying a reference voltage to the INA791x that deviates from the mid-point of the device supply voltage.

7.1.1.3 External Adjustable Gain Error

The INA791x features external adjustable gain with two external resistors as described in *Adjustable Gain Set Using External Resistors*. The tolerance of these external resistors contribute to the total gain error of the system. These resistors are recommended to be of same kind so that temperature drift of these resistor track closely. Equation 4 can be used for calculating total error contributed by two external gain resistors.

$$\mathrm{Error}_{G\_R} = \sqrt{2} \times \mathrm{Resistor}_{\mathrm{Tolerance}} + \mathrm{Resistor}_{\mathrm{drift}} \times \Delta\ T \tag{4}$$

7.1.1.4 Total Error Example 1

Table 7-1. Total Error Calculation: Example 1[(1)]

TERM	SYMBOL	EQUATION	TYPICAL VALUE
Initial input offset with Temp drift	I_{OS_T}	$I_{OS} + \frac{dI_{OS}}{dT} \times \Delta\ T$	30mA
Added input offset because of common-mode voltage	I_{OS_CM}	$\mathrm{CMRR} \times \lvert (V_{CM} - 48\ V) \rvert$	0µA
Added input offset because of reference voltage	I_{OS_REF}	$\mathrm{RVRR} \times \left\lvert \left(\frac{V_S}{2} - V_{REF} \right) \right\rvert$	0µA

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Table 7-1. Total Error Calculation: Example 1[(1)] (continued)

TERM	SYMBOL	EQUATION	TYPICAL VALUE
Total input offset Current	I_{OS_Total}	$\sqrt{(I_{OS\_T})^2 + (I_{OS\_CM})^2 + (I_{OS\_REF})^2}$	30mA
Error from input offset	$Error_{I_{OS}}$	$\frac{I_{OS\_Total}}{I_{Sense}} \times 100$	0.12%
Gain error with Gain drift	$Error_G$	$G_{Error} + G_{Error\_drift} \times \Delta T$	0.35%
Nonlinearity error	$Error_{Lin}$	—	0.01%
Total error	—	$\sqrt{(Error_{I_{OS}})^2 + (Error_G)^2 + (Error_{Lin})^2}$	0.38%

(1) The data for *Total Error Example 1* was taken with the INA791x, V_S = 5V, V_{CM} = 48V, V_{REF} = V_S / 2, T = 25°C, External Unity Gain (G = 20mV/A) and I_{SENSE} = 25A.

7.1.1.5 Total Error Example 2

Table 7-2. Total Error Calculation: Example 2[(1)]

TERM	SYMBOL	EQUATION	TYPICAL VALUE
Initial input offset with Temp drift	I_{OS_T}	$I_{OS} + \frac{dI_{OS}}{dT} \times \Delta T$	92.5mA
Added input offset because of common-mode voltage	I_{OS_CM}	$CMRR \times \lvert(V_{CM} - 48V)\rvert$	2.8mA
Added input offset because of reference voltage	I_{OS_REF}	$RVRR \times \left\lvert\left(\frac{V_S}{2} - V_{REF}\right)\right\rvert$	31.25mA
Total input offset Current	I_{OS_Total}	$\sqrt{(I_{OS\_T})^2 + (I_{OS\_CM})^2 + (I_{OS\_REF})^2}$	97.67mA
Error from input offset	$Error_{I_{OS}}$	$\frac{I_{OS\_Total}}{I_{Sense}} \times 100$	0.39%
Gain error with Gain drift	$Error_G$	$G_{Error} + G_{Error\_drift} \times \Delta T$	0.7%
Nonlinearity error	$Error_{Lin}$	—	0.01%
Total error	—	$\sqrt{(Error_{I_{OS}})^2 + (Error_G)^2 + (Error_{Lin})^2}$	0.8%

(1) The data for Total Error Example 2 was taken with the INA791x, V_S = 5V, V_{CM} = 12V, V_{REF} = 0V, T = 125°C, External Unity Gain (G = 20mV/A) and I_{SENSE} = 25A.

7.1.1.6 Total Error Example 3

Table 7-3. Total Error Calculation: Example 3[(1)]

TERM	SYMBOL	EQUATION	TYPICAL VALUE
Initial input offset with Temp drift	I_{OS_T}	$I_{OS} + \frac{dI_{OS}}{dT} \times \Delta T$	92.5mA
Added input offset because of common-mode voltage	I_{OS_CM}	$CMRR \times \lvert(V_{CM} - 48V)\rvert$	2.8mA
Added input offset because of reference voltage	I_{OS_REF}	$RVRR \times \left\lvert\left(\frac{V_S}{2} - V_{REF}\right)\right\rvert$	31.25mA
Total input offset Current	I_{OS_Total}	$\sqrt{(I_{OS\_T})^2 + (I_{OS\_CM})^2 + (I_{OS\_REF})^2}$	97.67mA
Error from input offset	$Error_{I_{OS}}$	$\frac{I_{OS\_Total}}{I_{Sense}} \times 100$	0.39%
Gain error with Gain drift	$Error_G$	$G_{Error} + G_{Error\_drift} \times \Delta T$	0.7%
Nonlinearity error	$Error_{Lin}$	—	0.01%

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Table 7-3. Total Error Calculation: Example 3(1) (continued)

TERM	SYMBOL	EQUATION	TYPICAL VALUE
External Gain Resistor Error + Drift	$Error_{G\_R}$	Equation 4	0.6%
Total error	—	$\sqrt{(Error_{IOS})^2 + (Error_{G\_R})^2 + (Error_{G})^2 + (Error_{Lin})^2}$	1.01%

(1) The data for *Total Error Example 3* was taken with the INA791x, V_S = 5V, V_{CM} = 12V, V_{REF} = 0V, T = 125°C, External Gain = 4 (Total Gain = 80mV/A), External Resistor Tolerance = 0.25%, External Resistor Drift = 25ppm/°C and I_{SENSE} = 25A.

7.2 Typical Applications

The INA791x offers advantages for multiple applications including the following:

- High common-mode range and excellent CMRR enables direct inline sensing
- Precision low-inductive, low-drift shunt eliminates the need for overtemperature system calibration
- Ultra-low offset and drift eliminates the necessity of calibration
- Wide supply range enables a direct interface with most microprocessors

7.2.1 High-Side, High-Drive, Solenoid Current-Sense Application

Challenges exist in solenoid drive current sensing that are similar to those in motor inline current sensing. In certain topologies, the current-sensing amplifier is exposed to the full-scale PWM voltage between ground and supply. The INA791x is an excellent choice for this type of application. The 400µΩ integrated shunt with a total system accuracy of 0.35% with a total system drift of 35ppm/°C provides system accuracy across temperature eliminating the need for system calibration at muliple temperatures.

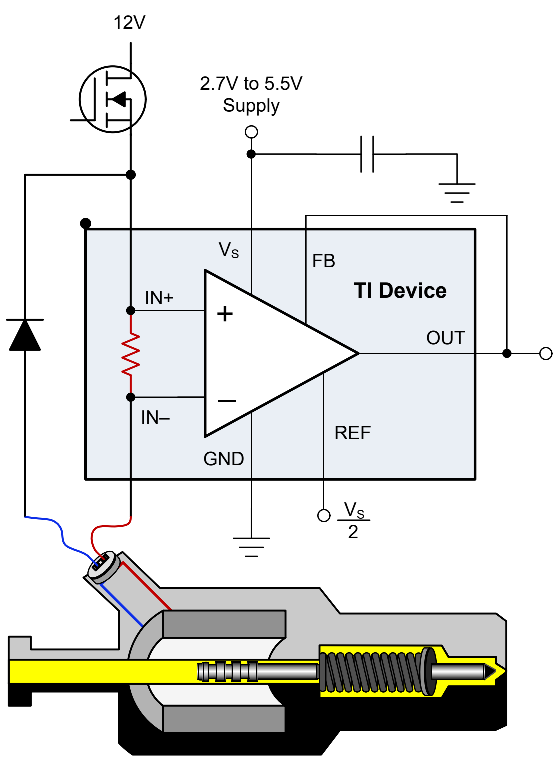

Figure 7-1. Solenoid Drive Application Circuit

7.2.1.1 Design Requirements

For this application, the INA791x measures current in the driver circuit of a 12V, 500mA hydraulic valve.

Table 7-4. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Common-mode voltage	12V
Maximum sense current	500mA
Power-supply voltage	3.3V

8 Power Supply Recommendations

The INA791x makes accurate measurements beyond the connected power-supply voltage (VS) because the inputs (IN+ and IN–) operate anywhere between –4V and +110V, independent of VS. For example, the VS power supply equals 5V and the common-mode voltage of the measured shunt can be as high as 110V. Although the common-mode voltage of the input can be beyond the supply voltage, the output voltage range of the INA791x is constrained to the supply voltage.

Place the power-supply bypass capacitor as close as possible to the supply and ground pins. The recommended value of this bypass capacitor is 0.1µF. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies. If the INA791x output is set to mid-supply, then take extreme care to minimize noise on the power supply.

ADVANCE INFORMATION

9 Layout Example

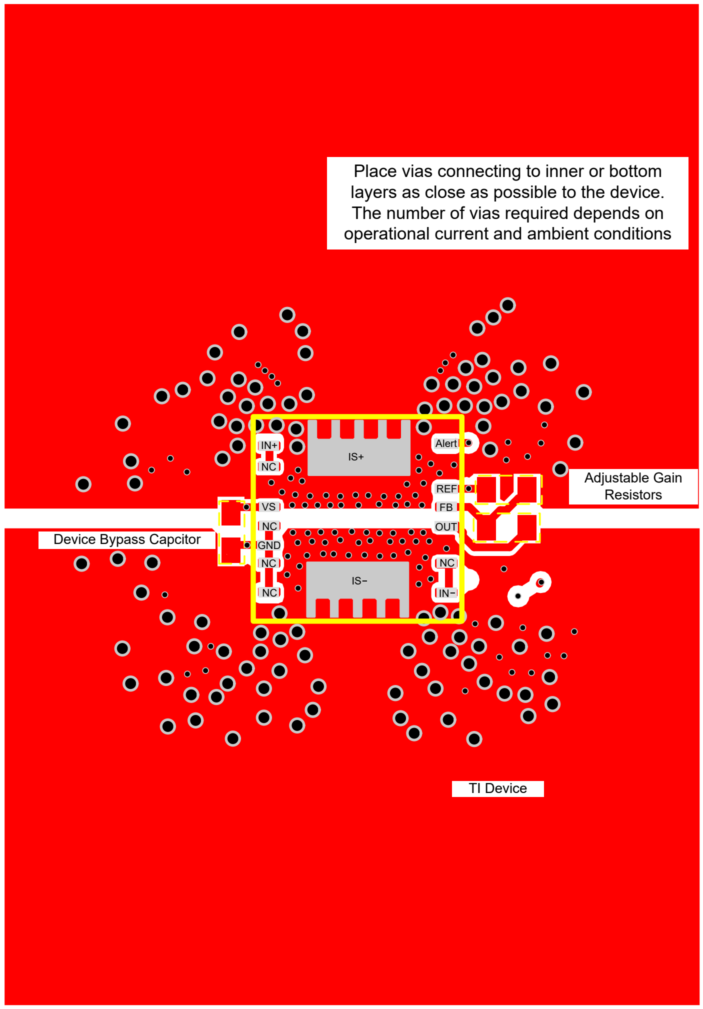

Figure 9-1. INA791x Layout Example

10 Layout Guidelines

- This device is specified for current handling of up to 50A over the entire –40°C to +125°C temperature range using a 2oz copper pour for the input power plane, as well as no external airflow passing over the device.
- The primary current-handling limitation for this device is how much heat is dissipated inside the package. Efforts to improve heat transfer out of the package and into the surrounding environment improve the ability of the device to handle currents of up to 50A over a wider temperature range.
- Heat transfer improvements primarily involve larger copper power traces and planes with increased copper thickness (2oz.), as well as providing airflow to pass over the device. Thermal vias help spread the current and power dissipated over multiple board layers. The INA791x evaluation module (EVM) features a 2oz copper pour for the planes, and is capable of supporting 50A at temperatures up to 125°C.
- The bypass capacitor must be placed close to device ground and supply pins, but can be moved farther out if needed to avoid cutting thermal planes. The recommended value of this bypass capacitor is 0.1µF. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies.

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation, see the following:

- Texas Instruments, INA79xEVM, EVM User's Guide

11.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Notifications* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.3 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

11.4 Trademarks

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11.5 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

11.6 Glossary

TI Glossary — This glossary lists and explains terms, acronyms, and definitions.

12 Revision History

DATE	REVISION	NOTE
May 2024	*	Initial release

13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most-current data available for the designated devices. This data is subject to change without notice and without revision of this document. For browser-based versions of this data sheet, see the left-hand navigation pane.

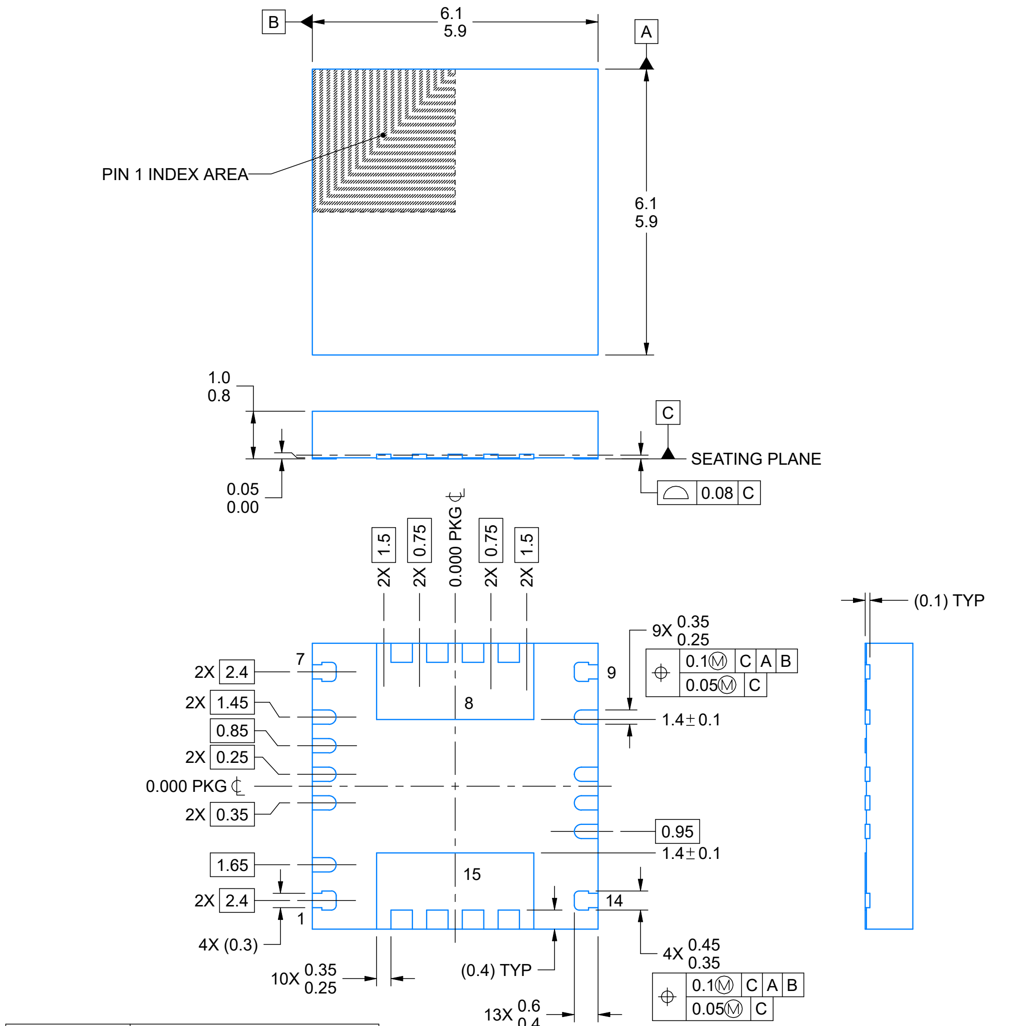
ADVANCE INFORMATION

PACKAGE OUTLINE

DEK0015A

VQFN - 1 mm max height

PLASTIC QUAD FLAT PACK - NO LEAD



PIN NUMBER	LEAD SIZE	
	LEAD WIDTH	LEAD LENGTH
1, 6, 8 & 14	0.35 - 0.45	0.40 - 0.60
2 - 5 & 9 - 12	0.25 - 0.35	0.40 - 0.60

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NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

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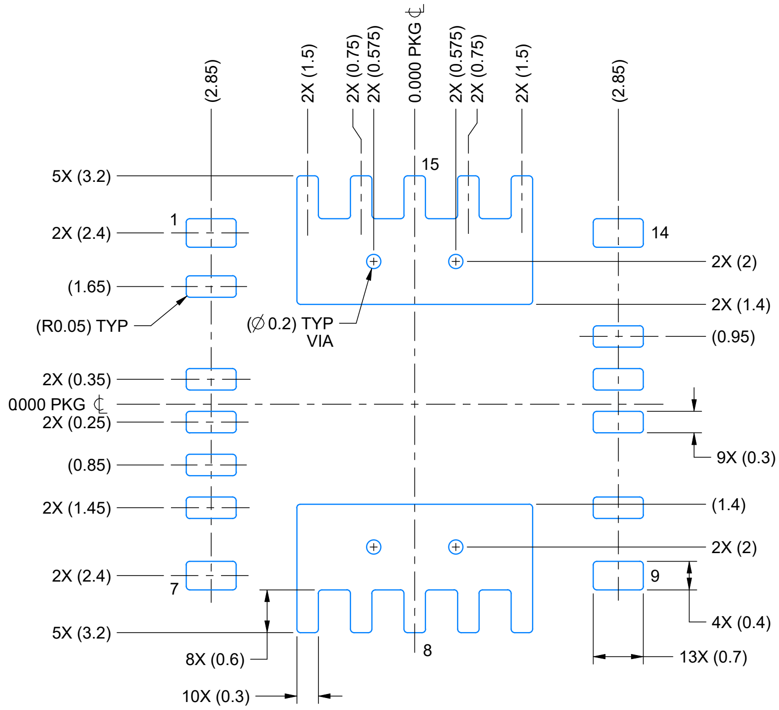
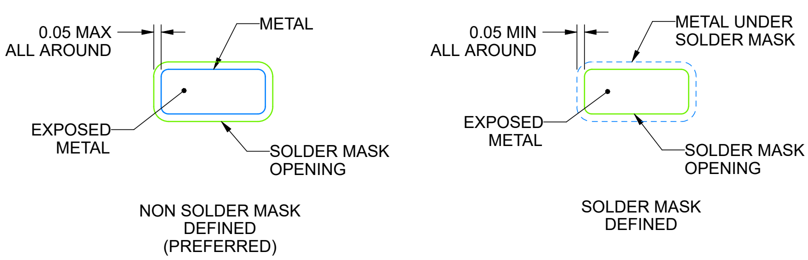
EXAMPLE BOARD LAYOUT

DEK0015A **VQFN - 1 mm max height**

PLASTIC QUAD FLAT PACK - NO LEAD



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE 12.000



SOLDER MASK DETAILS

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NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

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ADVANCE INFORMATION

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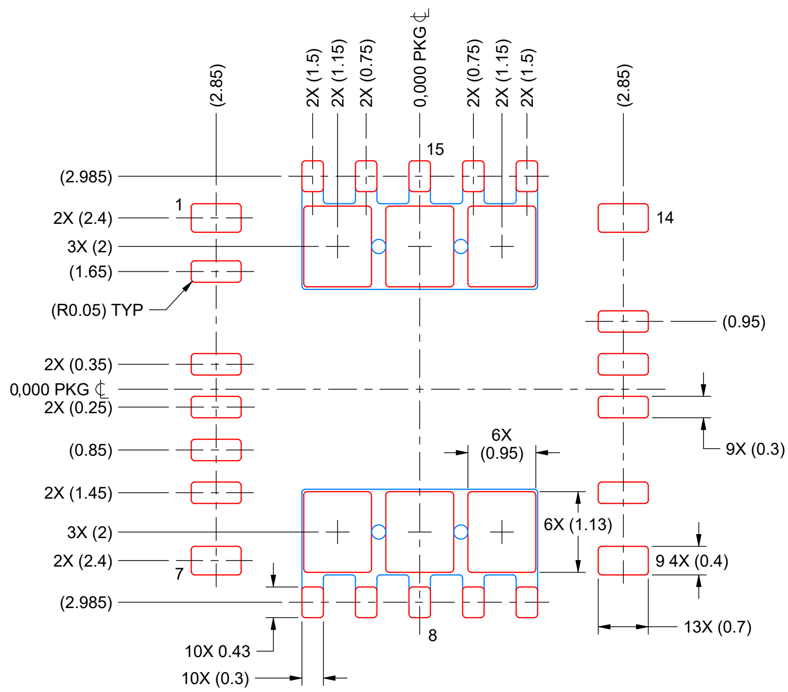
EXAMPLE STENCIL DESIGN

DEK0015A

VQFN - 1 mm max height

PLASTIC QUAD FLAT PACK - NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.1 mm THICK STENCIL
SCALE 12.000

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NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
PINA791BIDEKR	ACTIVE	VQFN	DEK	15	4000	TBD	Call TI	Call TI	-40 to 125		Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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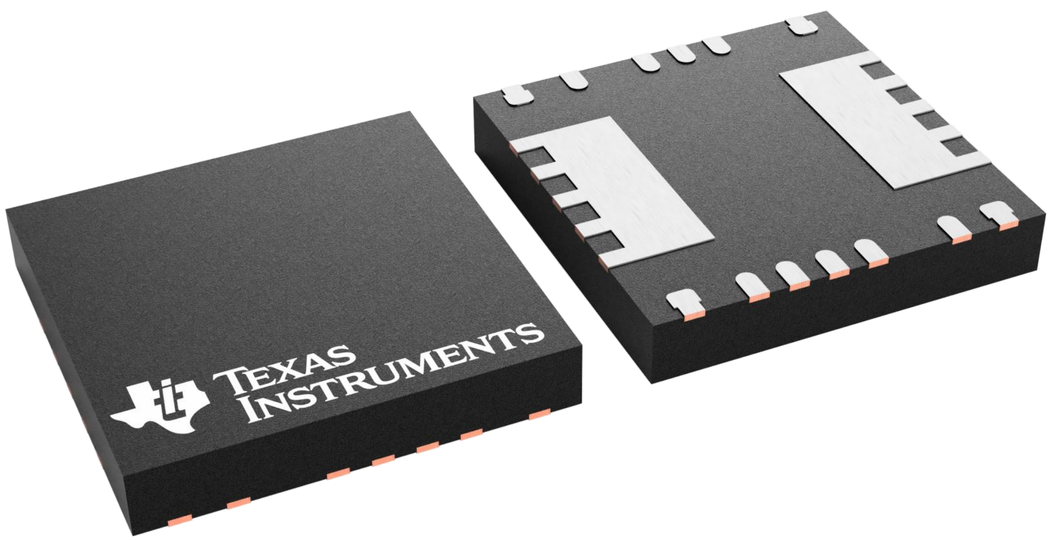
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

This image is a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.



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