

High-Current Battery Monitor Circuit: 0A – 10A, 0kHz – 10kHz, 18 Bit



Luis Chioye

Sense Resistor Current	INA Out, Amplifier Input	ADC Input	Digital Output ADS8910B
MinCurrent = ±50mA	Out = ±10mV	VoutDif = ±21.3mV	233 _H 563 ₁₀ , 3FDCB _H -564 ₀
MaxCurrent = +10A	Out = ±2V	VoutDif = ± 4.3V	1B851 ^H 112722 ₁₀ 247AE _H -112722 ₁₀

Table 1-1. Supply and Reference

Vs	Vee	Vref	Vcm
5.3 V <Vs <5.5V	0V	5V	2.5V

Design Description

This single-supply current sensing solution can measure a current signal in the range of ±50 mA to ±10 A across a shunt resistor. The current sense amplifier can measure shunt resistors over a wide common-mode voltage range from 0V to 75V. A fully differential amplifier (FDA) performs the single-ended to differential conversion and drives the SAR ADC differential input scale of ±5V at full data rate of 1MSPS. The values in the component selection section can be adjusted to allow for different current levels.

This circuit implementation is applicable in accurate voltage measurement applications such as battery maintenance systems, battery analyzers, *battery cell formation and test equipment*, *automatic test equipment*, and Remote Radio Units (RRU) in wireless base stations.

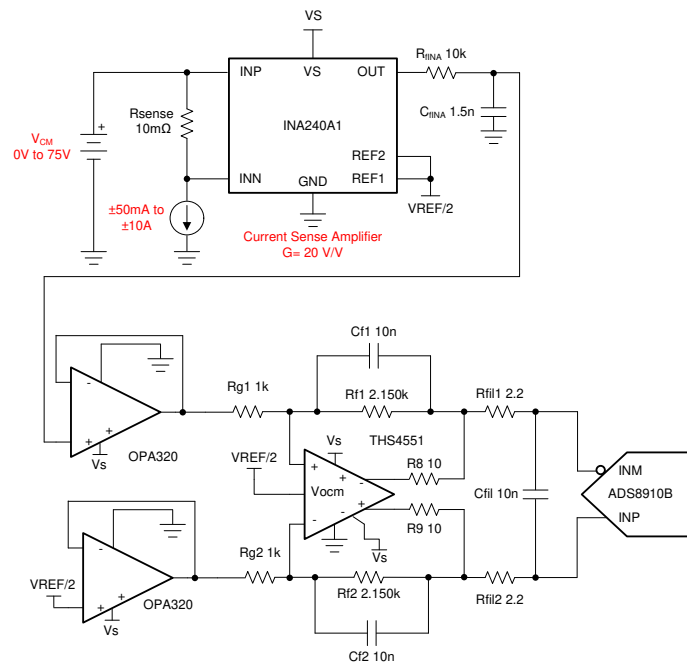


Table 1-2. Specifications

Error Analysis	Calculated	Simulated	Measured
Transient ADC Input Settling	> 1LSB > 38 μ V	6.6 μ V	N/A
Noise (at ADC Input)	221.8 μ V rms	207.3 μ V rms	227 μ V rms
Bandwidth	10.6kHz	10.71kHz	10.71kHz

Design Notes

- Determine the shunt sense resistor value and select the current sense amplifier based on the input current range and input common mode voltage requirements. This is covered in the *component selection* section.
- Determine the fully differential amplifier gain based on the current sense amplifier output, the ADC full-scale range input and the output swing specifications of the fully differential amplifier. This is covered in the *component selection* section.
- Select COG capacitors to minimize distortion.
- Use 0.1% 20ppm/ $^{\circ}$ C film resistors or better for good accuracy, low gain drift, and to minimize distortion.
- The TI Precision Labs training video series covers methods for error analysis. Review the following links for methods to minimize gain, offset, drift, and noise errors: [Error and Noise](#).
- The [TI Precision Labs – ADCs](#) training video series covers methods for selecting the charge bucket circuit R_{filt} and C_{filt} . These component values are dependent on the amplifier bandwidth, data converter sampling rate, and data converter design. The values shown here will give good settling and ac performance for the amplifier, gain settings, and data converter in this example. If the design is modified, select a different RC filter. Refer to [Introduction to SAR ADC Front-End Component Selection](#) for an explanation of how to select the RC filter for best settling and ac performance.

Component Selection for Current Sense Circuit

- Choose the R_{sense} resistor and find the gain for the current sense amplifier (bidirectional current).

$$R_{sh} = \frac{V_{sh(max)}}{I_{load(max)}} = \frac{100mV}{10A} = 0.01\Omega$$

$$\pm V_{out(range)} = \pm \frac{V_{REF}}{2} = \pm \frac{5V}{2} = \pm 2.5V$$

$$G_{INA} = \frac{\pm V_{out(range)}}{I_{load(max)} \times R_{sh}} = \frac{\pm 2.5V}{10A \times 0.01\Omega} = 25V/V$$

- Calculate the current sense amplifier output range.

$$V_{ina_outmax} = G_{INA} \times (I_{load(max)} \times R_{sh}) + \frac{V_{ref}}{2} = (20V/V) \times (10A \times 0.01\Omega) + \frac{5V}{2} = 4.5V$$

$$V_{ina_outmin} = G_{INA} \times (I_{load(max)} \times R_{sh}) + \frac{V_{ref}}{2} = (20V/V) \times (-10A \times 0.01\Omega) + \frac{5V}{2} = 0.5V$$

- Find ADC full-scale input range and results from step 3.

$$ADC_{Full} - \text{Scale Range} = \pm V_{REF} = \pm 5V$$

- Find FDA maximum and minimum output for linear operation.

$$0.23V < V_{out} < 4.77V \text{ from THS4551 output low/high specification for linear operation}$$

$$V_{out_FDA_max} = 4.77V - 0.23V = 4.54V \text{ Differential max output}$$

$$V_{out_FDA_min} = -V_{out_FDA_max} = -4.54V \text{ Differential min output}$$

- Find differential gain based on ADC full-scale input range, FDA output range and results from step 3.

$$\text{Gain} = \frac{V_{out_FDA_max} - V_{out_FDA_min}}{V_{INA_outmax} - V_{INA_outmin}} = \frac{4.54V - (-4.54V)}{4.5V - 0.5V} = 2.77V/V$$

Gain $\approx 2.15V/V$ for margin

6. Find standard resistor values for differential gain.

$$\text{Gain}_{\text{FDA}} = \frac{R_f}{R_g} = 2.15V/V$$

$$\frac{R_f}{R_g} = 2.15V/V = \frac{2.15k\Omega}{1.00k\Omega} = 2.15V/V$$

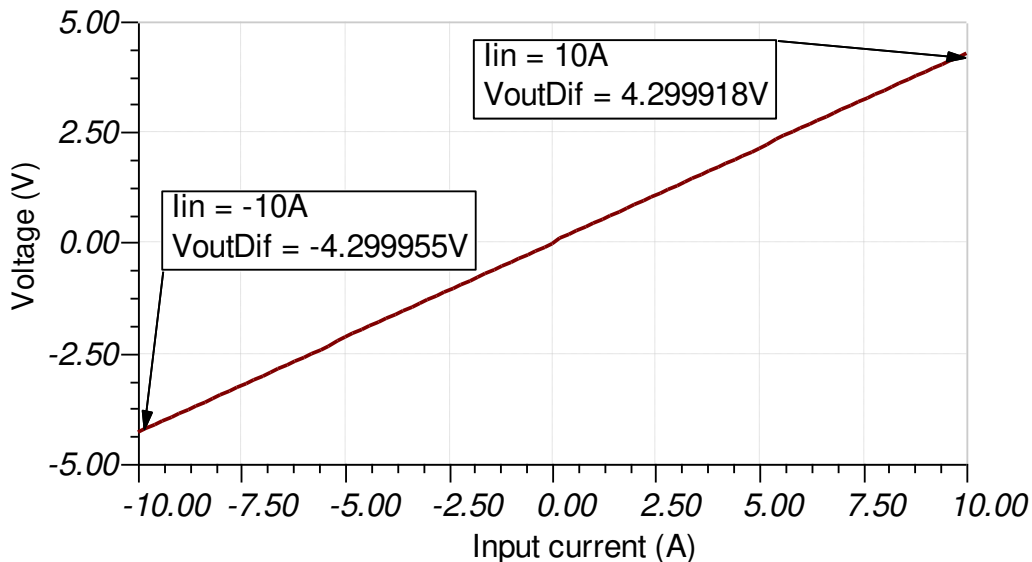
7. Find R_{fINA} , C_{fINA} for cutoff frequency.

$$C_{\text{fINA}} = \frac{1}{2 \times \pi \times f_c \times R_{\text{fINA}}} = \frac{1}{2 \times \pi \times 10\text{kHz} \times 10k\Omega} = 1.591\text{nF} \text{ or } 1.5\text{nF} \text{ for standard value}$$

$$f_{\text{fina}} = \frac{1}{2 \times \pi \times C_{\text{fINA}} \times R_f} = \frac{1}{2 \times \pi \times 1.5\text{nF} \times 10k\Omega} = 10.6\text{kHz}$$

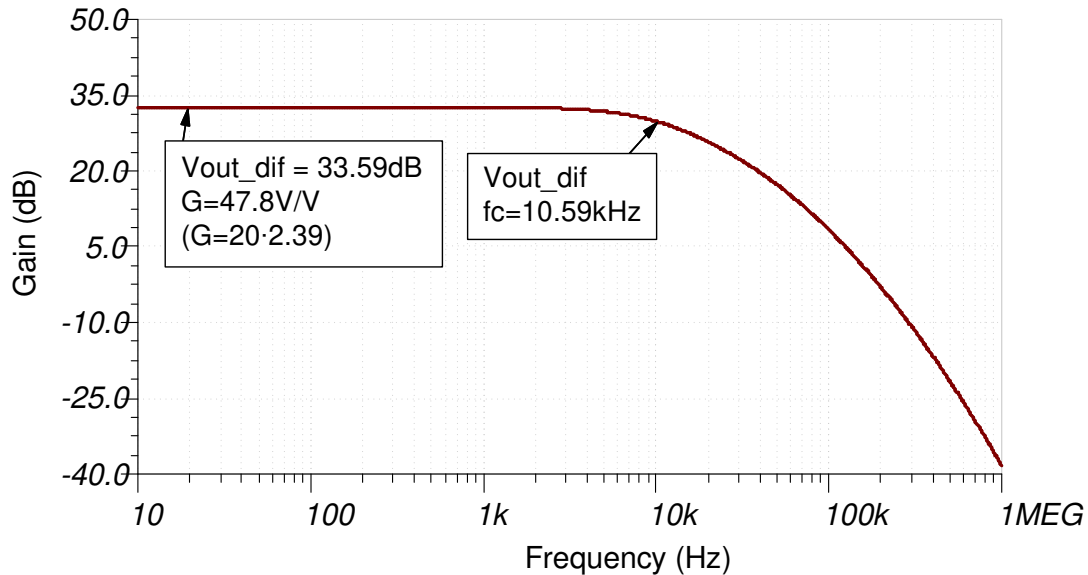
Fully Differential DC Transfer Characteristics

The following graph shows a linear output response for inputs from $-10A$ to $+10A$.



AC Transfer Characteristics

The bandwidth is simulated to be 10.5kHz and the gain is 32.66dB which is a linear gain of 43V/V ($G = 20 \times 2.15V/V$).



Noise Simulation

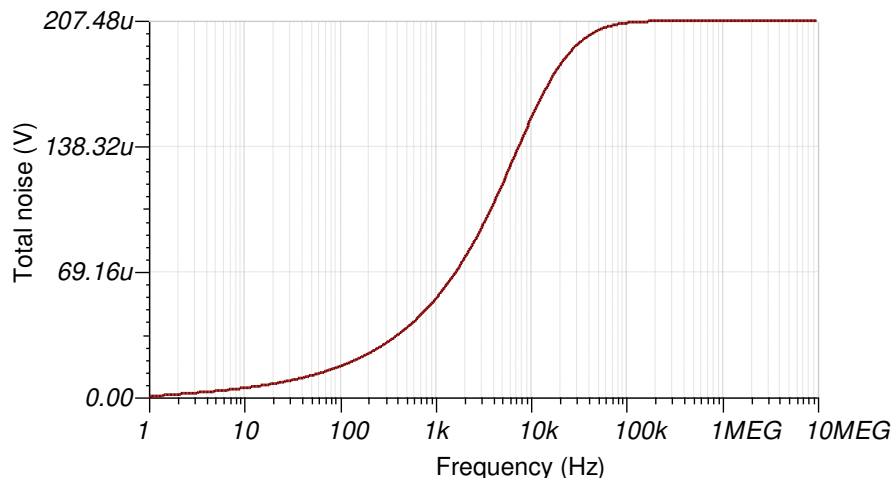
The following simplified noise calculation is provided for a rough estimate. Since the current sense amplifier INA240 is the dominant source of noise, the noise contribution of the OPA320 buffers and THS4521 is omitted in the noise estimate. We neglect resistor noise in this calculation as it is attenuated for frequencies greater than 10.6kHz.

$$f_c = \frac{1}{2\pi \times R_{fINA} \times C_{fINA}} = \frac{1}{2\pi \times 10k\Omega \times 1.5nF} = 10.6kHz$$

$$E_{nINA240} = e_{nINA240} \times G_{INA} \times \sqrt{K_n \times f_c} = (40nV \div \sqrt{Hz}) \times (20V \div V) \times \sqrt{1.57 \times 10.6kHz} = 103.2\mu V$$

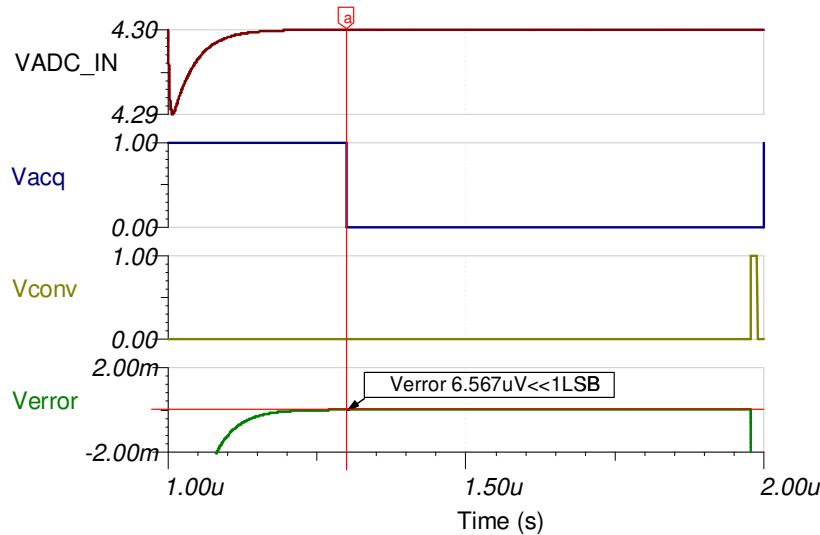
$$E_{nADCIN} = E_{nINA240} \times G_{FDA} = (103.2\mu V_{rms}) \times (2.15V/V) = 221.8\mu V_{rms}$$

Note that calculated and simulated match well. Refer to [Noise - Lab](#) for detailed theory on amplifier noise calculations, and [ADC noise measurement, methods and parameters](#) for data converter noise.



Transient ADC Input Settling Simulation

The following simulation shows settling to a 10-A DC input signal (ADC differential input signal +4.3V). This type of simulation shows that the sample and hold kickback circuit is properly selected. Refer to [Final SAR ADC Drive Simulations](#) for detailed theory on this subject.



Design Featured Devices:

Device	Key Features	Link	Similar Devices
ADS8910B (1)	18-bit resolution, 1-Msps sample rate, integrated reference buffer, fully differential input, Vref input range 2.5V to 5V	18-Bit, 1-MSPS, 1-Ch SAR ADC with Internal VREF Buffer, Internal LDO and Enhanced SPI Interface	Precision ADCs
INA240	High- and low-Side, bi-directional, zero-drift current sense amp, GainError = 0.20%, Gain = 20V/V, wide common-mode = -4V to 80V	-4 to 80V, bidirectional, ultra-precise current sense amplifier with enhanced PWM rejection	Instrumentation amplifiers
THS4551	Fully differential amplifier (FDA), 150-MHz bandwidth, Rail-to-Rail output, VosDriftMax = 1.8 $\mu\text{V}/^\circ\text{C}$, $e_n = 3.3 \text{ nV}/\text{rtHz}$	Low Noise, Precision, 150MHz, Fully Differential Amplifier	Operational amplifiers (op amps)
OPA320	20-MHz bandwidth, Rail-to-Rail with zero crossover distortion, VosMax = 150 μV , VosDriftMax = 5 $\mu\text{V}/^\circ\text{C}$, $e_n = 7 \text{ nV}/\text{rtHz}$	Precision, zero-crossover, 20-MHz, 0.9-pA Ib, RRIO, CMOS operational amplifier	Operational amplifiers (op amps)
REF5050	3 ppm/ $^\circ\text{C}$ drift, 0.05% initial accuracy, 4 $\mu\text{Vpp}/\text{V}$ noise	5-V, 3-$\mu\text{Vpp}/\text{V}$ noise, 3-ppm/$^\circ\text{C}$ drift precision series voltage reference	Series voltage references

(1) The REF5050 can be directly connected to the ADS8910B without any buffer because the ADS8910B has a built in internal reference buffer. Also, the REF5050 has the required low noise and drift for precision SAR applications. The INA240 offers high common-mode range and low gain error in current sensing solutions. The THS4551 is commonly used in high-speed precision fully differential SAR applications as it has sufficient bandwidth to settle to charge kickback transients from the ADC input sampling. The OPA320 is required to isolate the INA240 from any residual charge kickback at the inputs of the FDA.

Link to Key Files

Texas Instruments, [ADS8900B Design File](#), software support

Trademarks

All trademarks are the property of their respective owners.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2024, Texas Instruments Incorporated