

Low-side bidirectional current sensing circuit with MSP430™ smart analog combo

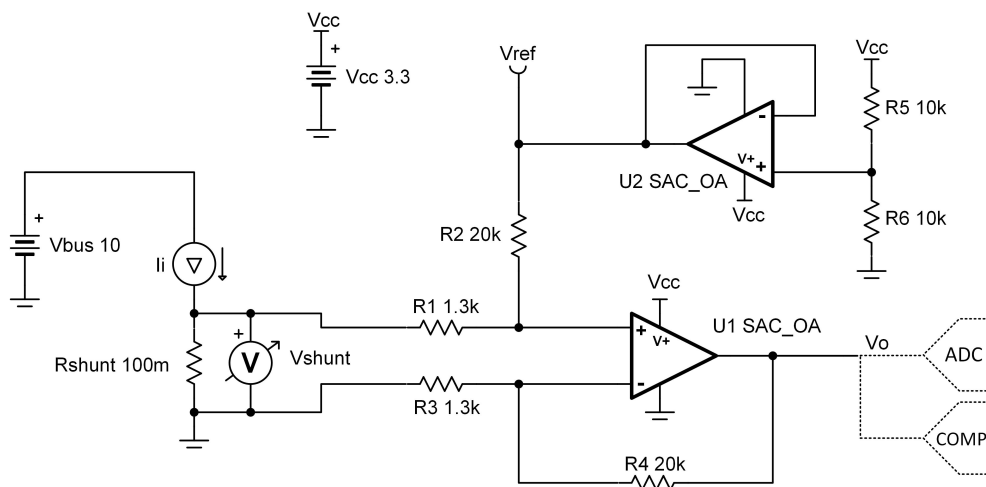
Design Goals

Input		Output		Supply	
I_{iMin}	I_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ref}
-1 A	1 A	100 mV	3.2 V	3.3 V	1.65 V

Design Description

Some MSP430™ microcontrollers (MCUs) contain configurable integrated signal chain elements such as op-amps, DACs, and programmable gain stages. These elements make up a peripheral called the Smart Analog Combo (SAC). For information on the different types of SACs and how to leverage their configurable analog signal chain capabilities, visit [MSP430 MCUs Smart Analog Combo Training](#). To get started with your design, download the [Low-side Bidirectional Current Sensing Design Files](#).

This single-supply low-side, bidirectional current sensing solution can accurately detect load currents from -1 A to 1 A. The linear range of the output is from 100 mV to 3.2 V. Low-side current sensing keeps the common-mode voltage near ground, and is thus most useful in applications with large bus voltages. This design leverages two of the four integrated op-amp blocks (SACs) in the [MSP430FR2355](#) MCU. One SAC_L3 peripheral is configured as a general purpose op-amp to amplify the voltage across the shunt resistor, while the other is configured as a buffer to provide the bias voltage (V_{ref}). The latter SAC_L3 block can also be configured in DAC buffer mode to provide V_{ref} , replacing the external voltage divider circuit. The output of the circuit can be internally or externally connected to other integrated peripherals in the [MSP430FR2355](#) MCU. For example, the analog-to-digital converter (ADC) window comparator can sample this output periodically (with no CPU intervention) and trigger an interrupt when the signal crosses a threshold.



Design Notes

- To minimize errors, set $R_3 = R_1$ and $R_4 = R_2$.
- Use precision resistors for higher accuracy.
- Set output range based on linear output swing (see A_{oI} specification).
- Low-side sensing should not be used in applications where the system load cannot withstand small ground disturbances or in applications that need to detect load shorts.
- In the schematic above, the first SAC_L3 peripheral in the MSP430FR2355 MCU (U1) is configured in general purpose mode. The second SAC_L3 peripheral (U2) is also configured in general purpose mode, but with an external voltage divider.
- It is recommended to use the DAC buffer configuration for U2 (as seen in the code examples in the [Low-side Bidirectional Current Sensing Design Files](#)) to provide V_{ref} instead of using the external voltage divider circuit.
- This solution can also be implemented using the MSP430FR2311 device by using the internal transimpedance amplifier for U1, and the SAC_L1 op-amp for U2.
- The [Low-side Bidirectional Current Sensing Design Files](#) include code examples showing how to properly initialize the SAC peripherals.

Design Steps

1. Determine the transfer equation given $R_4 = R_2$ and $R_1 = R_3$.

$$V_o = (I_i \times R_{shunt} \times \frac{R_4}{R_3}) + V_{ref}$$

$$V_{ref} = V_{cc} \times (\frac{R_6}{R_5 + R_6})$$

2. Determine the maximum shunt resistance.

$$R_{shunt} = \frac{V_{shunt}}{I_{imax}} = \frac{100mV}{1 A} = 100m\Omega$$

3. Set reference voltage.

- a. Because the input current range is symmetric, the reference should be set to mid supply. Therefore, make R_5 and R_6 equal.

$$R_5 = R_6 = 10k\Omega$$

4. Set the difference amplifier gain based on the op amp output swing. The op amp output can swing from 100 mV to 3.2 V, given a 3.3-V supply.

$$\text{Gain} = \frac{V_{oMax} - V_{oMin}}{R_{shunt} \times (I_{imax} - I_{imin})} = \frac{3.2V - 100mV}{100m\Omega \times (1 A - (-1 A))} = 15.5 \frac{V}{V}$$

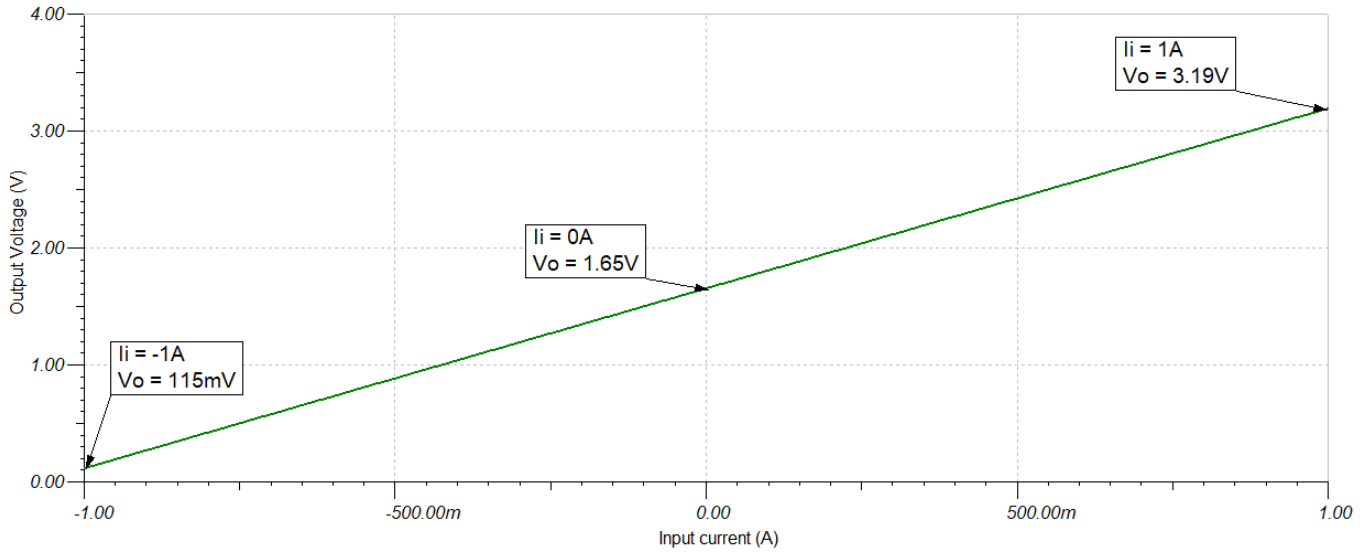
$$\text{Gain} = \frac{R_4}{R_3} = 15.5 \frac{V}{V}$$

Choose $R_1 = R_3 = 1.3k\Omega$ (Standard Value)

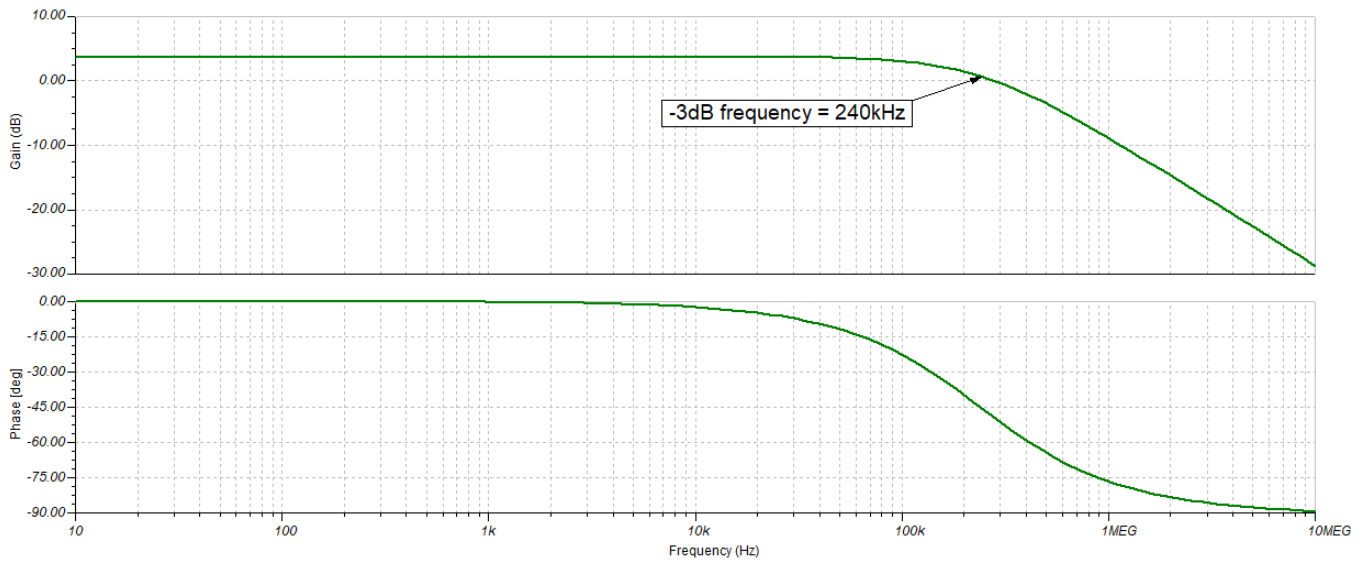
$$R_2 = R_4 = 15.5 \frac{V}{V} \times 1.3k\Omega = 20.15 k\Omega \approx 20k\Omega \text{ (Standard Value)}$$

Design Simulations

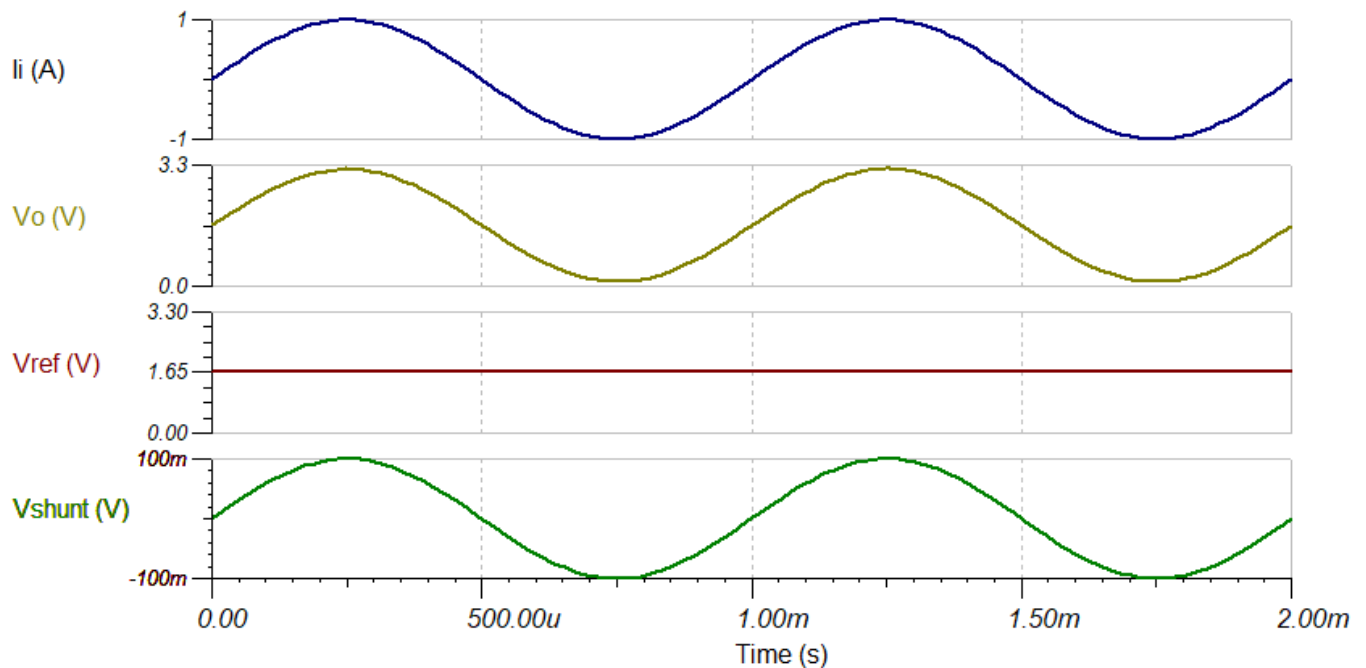
DC Simulation Results



Closed Loop AC Simulation Results



Transient Simulation Results



Target Applications

[Motor Drives](#)

[Servo Drive Functional Safety Module](#)

[Merchant Battery Charger](#)

[Battery Pack: Cordless Power Tool](#)

[Battery Pack: E-Bike/E-Scooter/Light Electric Vehicle \(LEV\)](#)

Design References

- [1. MSP430 Low-side Bidirectional Current Sensing Circuit Code Examples and SPICE Simulation File](#)
- [2. Analog Engineer's Circuit Cookbooks](#)
- [3. MSP430FR2311 TINA-TI Spice Model](#)
- [4. MSP430 MCUs Smart Analog Combo Training](#)



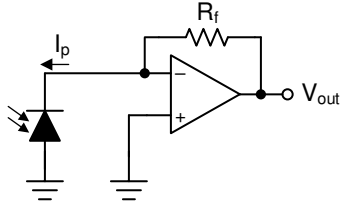
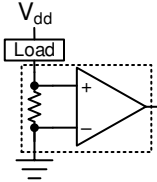
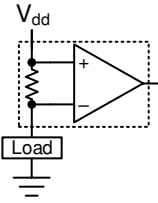
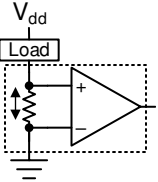

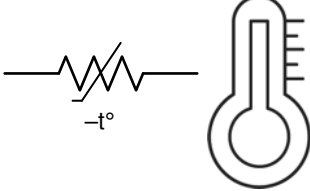
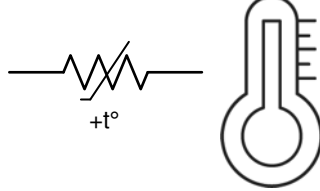
Design Featured Op Amp

MSP430FRxx Smart Analog Combo		
	MSP430FR2311 SAC_L1	MSP430FR2355 SAC_L3
V_{CC}	2.0 V to 3.6 V	
V_{CM}	-0.1 V to $V_{CC} + 0.1$ V	
V_{out}	Rail-to-rail	
V_{os}	± 5 mV	
A_{OL}	100 dB	
I_q	350 μ A (high-speed mode)	
	120 μ A (low-power mode)	
I_b	50 pA	
UGBW	4 MHz (high-speed mode)	2.8 MHz (high-speed mode)
	1.4 MHz (low-power mode)	1 MHz (low-power mode)
SR	3 V/ μ s (high-speed mode)	
	1 V/ μ s (low-power mode)	
Number of channels	1	4
http://www.ti.com/product/MSP430FR2311		
http://www.ti.com/product/MSP430FR2355		

Design Alternate Op Amp

MSP430FR2311 Transimpedance Amplifier	
V_{CC}	2.0 V to 3.6 V
V_{CM}	-0.1 V to $V_{CC}/2$ V
V_{out}	Rail-to-rail
V_{os}	± 5 mV
A_{OL}	100 dB
I_q	350 μ A (high-speed mode)
	120 μ A (low-power mode)
I_b	5 pA (TSSOP-16 with OA-dedicated pin input)
	50 pA (TSSOP-20 and VQFN-16)
UGBW	5 MHz (high-speed mode)
	1.8 MHz (low-power mode)
SR	4 V/ μ s (high-speed mode)
	1 V/ μ s (low-power mode)
Number of channels	1
http://www.ti.com/product/MSP430FR2311	

Related MSP430 Circuits

<p>Low-noise and long-range PIR sensor conditioner circuit</p> 	<p>Bridge amplifier circuit</p> 	<p>Transimpedance amplifier circuit</p> 
<p>Single-supply, low-side, unidirectional current-sensing circuit</p> 	<p>High-side current sensing with discrete difference amplifier circuit</p> 	<p>Low-side, bidirectional current-sensing circuit</p> 
<p>Half-wave rectifier circuit</p> 	<p>Temperature sensing with NTC thermistor circuit</p> 	<p>Temperature sensing with PTC thermistor circuit</p> 

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from November 15, 2019 to March 6, 2020

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- Added *Related MSP430 Circuits* section..... 6
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