

Low-Side Bidirectional Current Sensing Circuit with MSP430™ Smart Analog Combo



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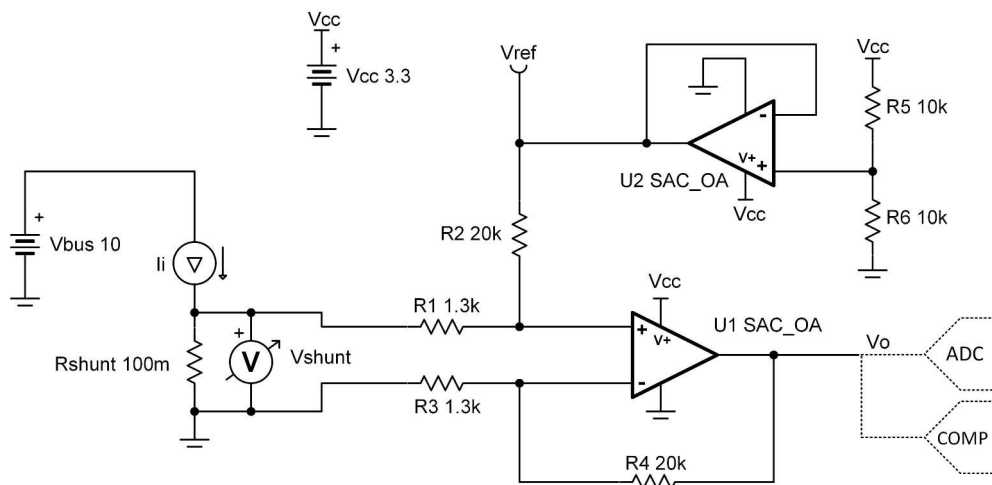
Design Goals

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

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 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 method accurately detects load currents from -1A to 1A. The linear range of the output is from 100mV to 3.2V. 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).
- Do not use low-side sensing 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.
- 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 option 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 $R_1 = R_3$.

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

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

2. Determine the maximum shunt resistance.

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

3. Set reference voltage. Because the input current range is symmetric, set the reference 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 is able to swing from 100mV to 3.2V, given a 3.3-V supply.

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

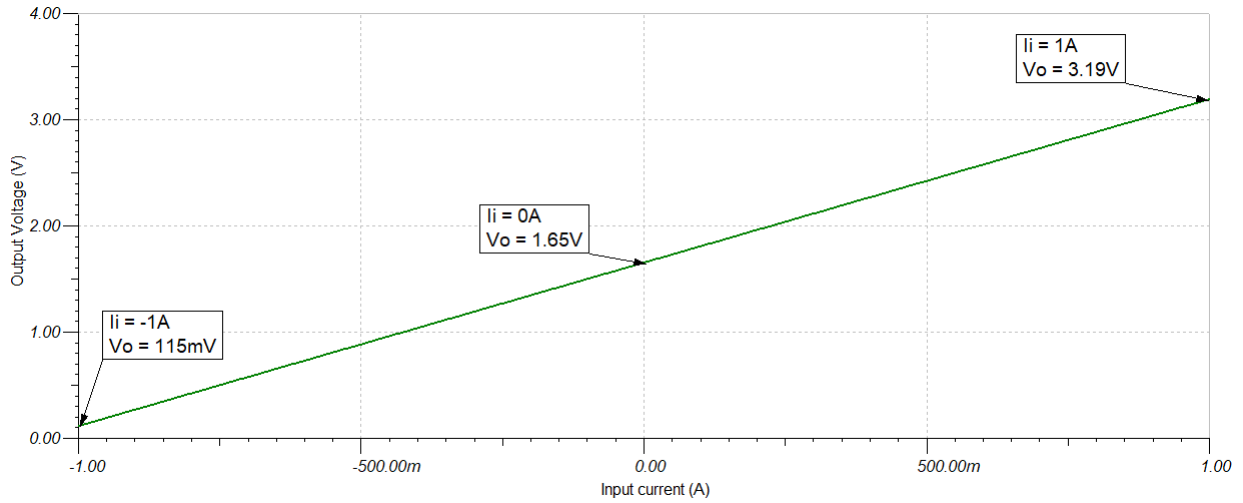
$$\text{Gain} = \frac{R_4}{R_3} = 15.5 \frac{\text{V}}{\text{V}}$$

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

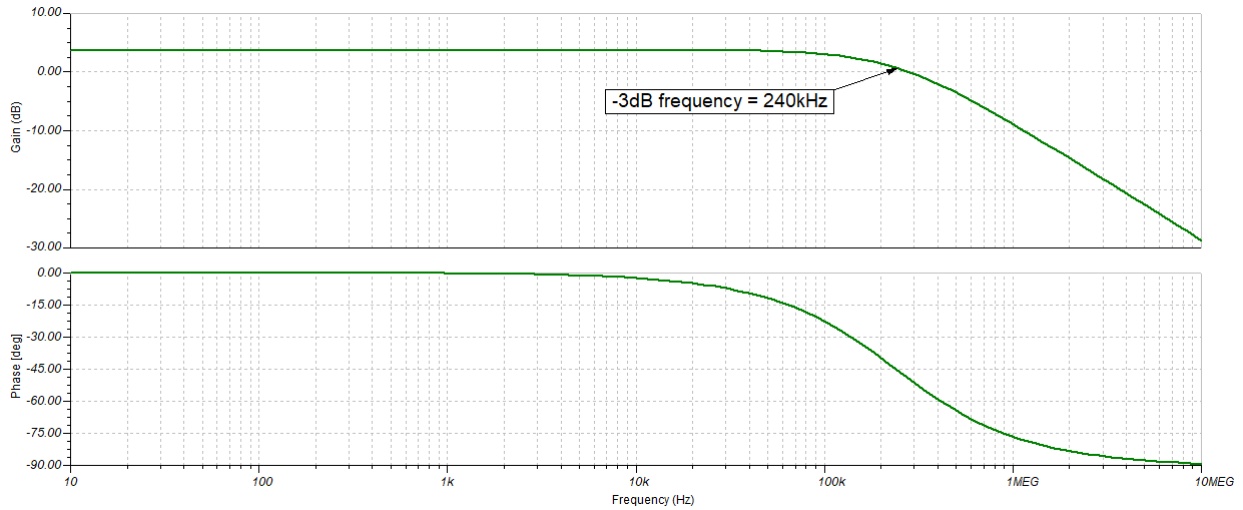
$$R_2 = R_4 = 15.5 \frac{\text{V}}{\text{V}} \times 1.3k\Omega = 20.15 \text{ k}\Omega \approx 20k\Omega \text{ (Standard Value)}$$

Design Simulations

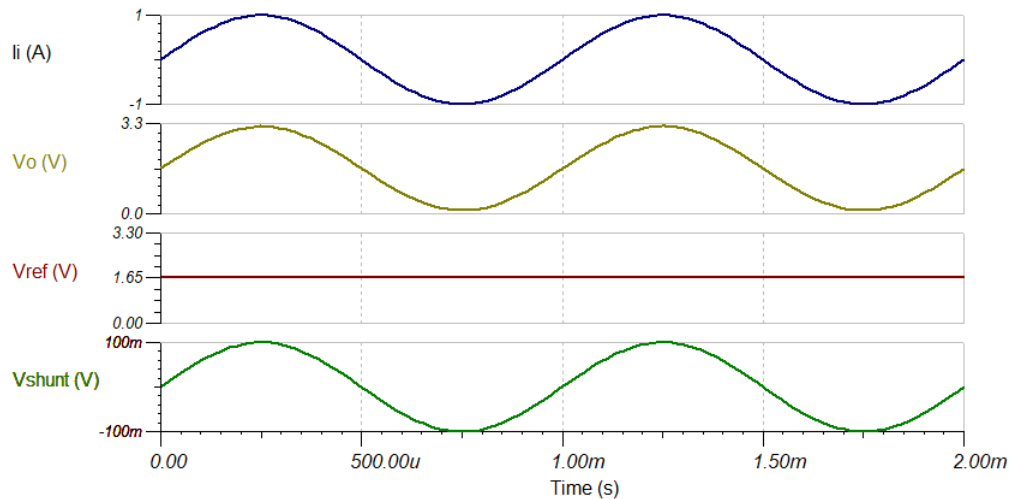
DC Simulation Results



Closed Loop AC Simulation Results



Transient Simulation Results



Target Applications

- [Motor Drives](#)
- [Servo Drive Functional Safety Module](#)
- [Battery Charger](#)
- [Battery Pack: Cordless Power Tool](#)
- [HEV/EV battery-management system \(BMS\)](#)

Design References

1. Texas Instruments, [MSP430 Low-side Bidirectional Current Sensing Circuit](#), code examples and SPICE simulation file
2. Texas Instruments, [16MHz integrated analog microcontroller with 3.75-KB FRAM, Op Amp, TIA, comparator with DAC, 10-bit ADC](#), product page
3. Texas Instruments, [MSP430 MCUs Smart Analog Combo Training](#), video



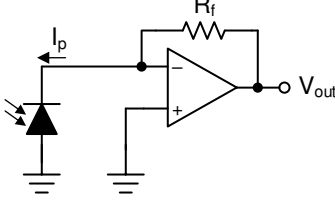
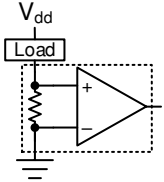
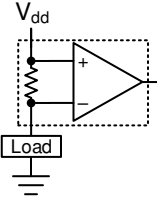
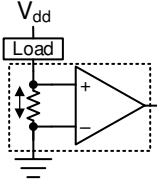

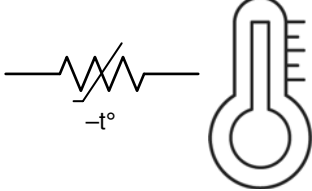
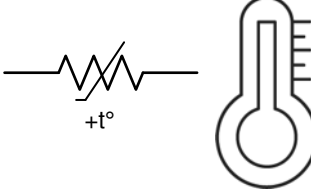
Design Featured Op Amp

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

Design Alternate Op Amp

MSP430FR2311 Transimpedance Amplifier	
V_{CC}	2.0V to 3.6V
V_{CM}	-0.1V to $V_{CC}/2V$
V_{out}	Rail-to-rail
V_{os}	$\pm 5mV$
A_{OL}	100dB
I_q	350 μA (high-speed mode)
	120 μA (low-power mode)
I_b	5pA (TSSOP-16 with OA-dedicated pin input)
	50pA (TSSOP-20 and VQFN-16)
UGBW	5MHz (high-speed mode)
	1.8MHz (low-power mode)
SR	4V/ μs (high-speed mode)
	1V/ μs (low-power mode)
Number of channels	1
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> 

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Revision History

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

Changes from Revision A (March 2020) to Revision B (October 2024) Page

- Updated the format for tables, figures, and cross-references throughout the document..... 1
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Changes from Revision * (November 2019) to Revision A (March 2020) Page

- Added *Related MSP430 Circuits* section.....1
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