Analog Engineer's Circuit

Transimpedance Amplifier Circuit with MSP430™ Smart Analog Combo

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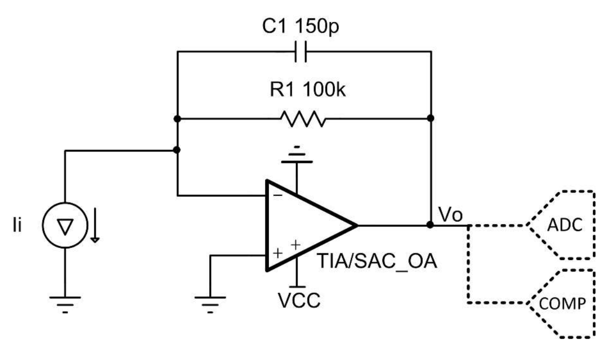
Design Goals

Input		Output		BW	Supply	
I_{iMin}	I_{iMax}	V_{oMin}	V_{oMax}	f_p	V_{cc}	V_{ee}
0 A	30 µA	0.2V	3.2V	10 kHz	3.3V	0V

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, see the *MSP430 MCUs Smart Analog Combo* video. To get started with your design, download the *MSP430 Transimpedance Amplifier Circuit Design Files*.

The transimpedance op amp circuit configuration converts an input current source into an output voltage. The current to voltage gain is based on the feedback resistance. The circuit can maintain a constant voltage bias across the input source as the input current changes, which benefits many sensors. The characteristics of the Transimpedance Amplifier (TIA) module in MSP430FR2311 make it especially suited for this functionality; however, this circuit can also be implemented with the MSP430FR2311, or with the MSP430FR2355 with additional built-in DAC and PGA capabilities. The output of these integrated amplifiers can be sampled directly by the on-board ADC or monitored by the on-board comparator for further processing inside the MCU.



Design Notes

- An op amp with low input bias current reduces DC errors.
- A bias voltage can be added to the non-inverting input to set the output voltage for 0-A input currents. The integrated 12-bit DAC in MSP430FR2355 SAC_L3 can be used for this purpose.
- Operate within the linear output voltage swing (see A_{ol} specification) to minimize non-linearity errors.
- If the fix is implemented with the MSP430FR2311, this circuit can be realized by the TransImpedance Amplifier (TIA) module, or by the SAC_L1.
- If the fix is implemented with the MSP430FR2355 SAC_L3, the op-amp should be configured in general-purpose mode.

- The *MSP430 Transimpedance Amplifier Circuit Design Files* include code examples showing how to properly initialize the peripherals.

Design Steps

1. Select the gain resistor.

$$R_1 = \frac{V_{oMax} - V_{oMin}}{I_{iMax}} = \frac{3.2V - 0.2V}{30\mu A} = 100k\Omega$$

2. Select the feedback capacitor to meet the circuit bandwidth.

$$C_1 \le \frac{1}{2 \times \pi \times R_1 \times f_p}$$

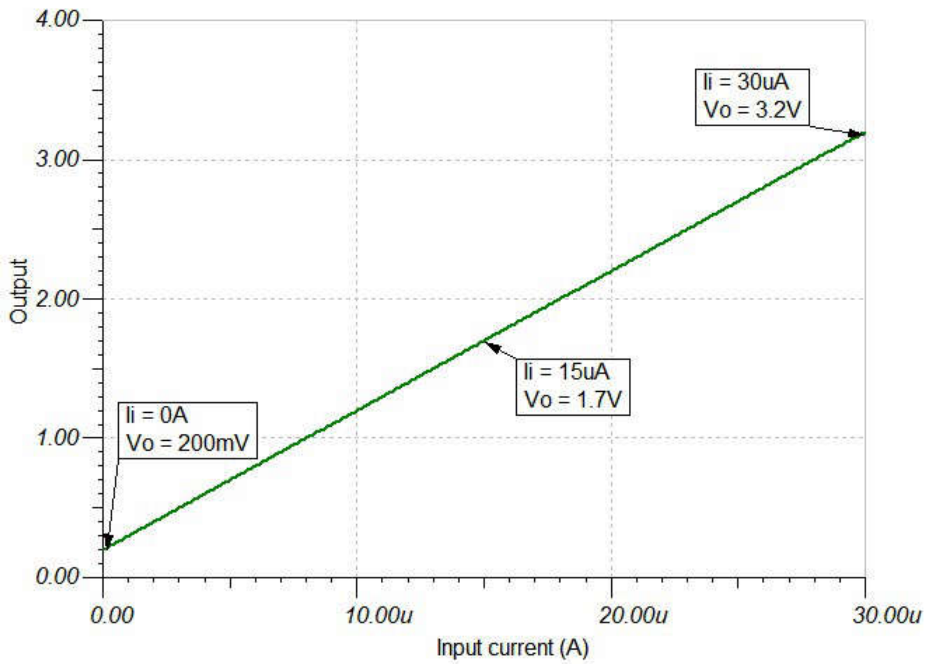
$$C_1 \le \frac{1}{2 \times \pi \times 100k\Omega \times 10kHz} \le 159pF \approx 150pF\ (\text{Standard Value})$$

3. Calculate the necessary op amp gain bandwidth (GBW) for the circuit to be stable.

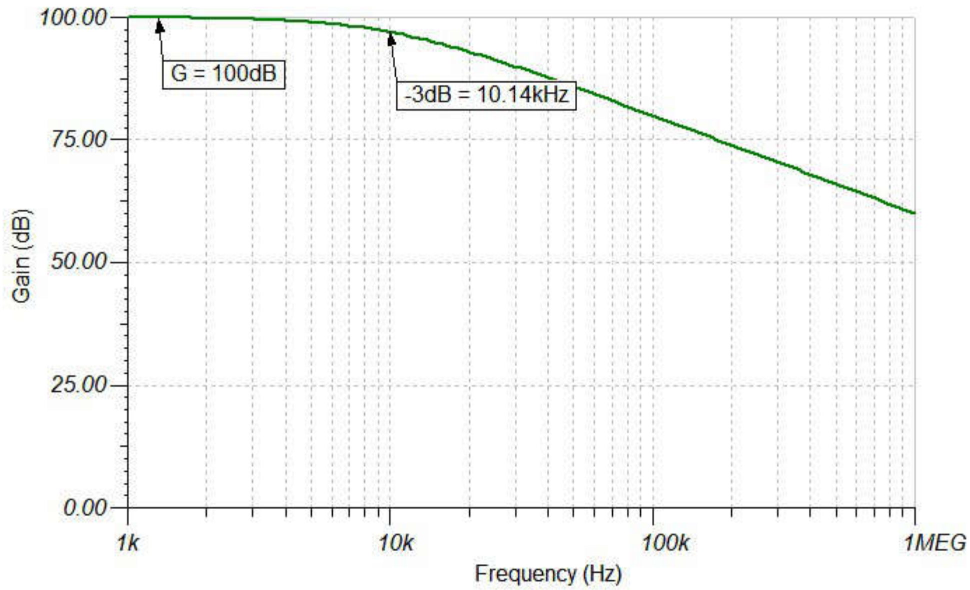
$$GBW > \frac{C_{in} + C_1}{2 \times \pi \times R_1 \times {C_1}^2} > \frac{7pF + 150pF}{2 \times \pi \times 100k\Omega \times (150pF)^2} > 11.10kHz$$

Design Simulations

DC Simulation Results



AC Simulation Results



Target Applications

- *Smoke and Heat Detectors*
- *Gas Detectors*
- *Motion Detectors*
- *Pulse Oximeters*
- *Blood Glucose Monitors*

Design References

1. Texas Instruments, *MSP430 Transimpedance Amplifier*, code examples and SPICE simulation files
2. Texas Instruments, *MSP430FR2311 16MHz integrated analog microcontroller with 3.75KB FRAM, Op Amp, TIA, comparator with DAC, 10-bit ADC*, product page
3. Texas Instruments, *MSP430 MCUs Smart Analog Combo*, video

Design Featured 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}	±5mV
A_{OL}	100dB
I_q	350µA (high-speed mode)
	120µA (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

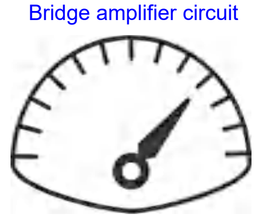
Design Alternate Op Amp

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

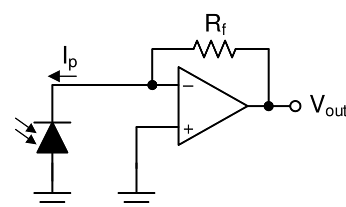
Related MSP430 Circuits

Low-noise and long-range PIR sensor conditioner circuit

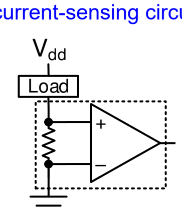
Bridge amplifier circuit



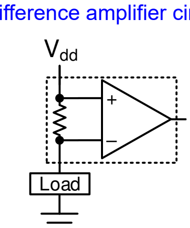
Transimpedance amplifier circuit



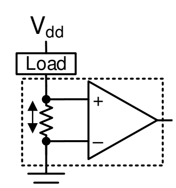
Single-supply, low-side, unidirectional current-sensing circuit



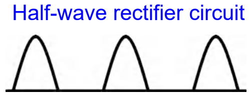
High-side current sensing with discrete difference amplifier circuit



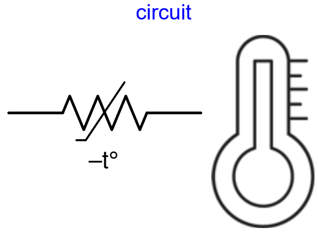
Low-side, bidirectional current-sensing circuit



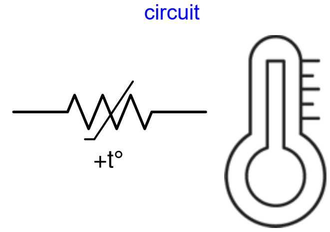
Half-wave rectifier circuit



Temperature sensing with NTC thermistor circuit



Temperature sensing with PTC thermistor circuit



Trademarks

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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

Changes from Revision * (December 2019) to Revision A (March 2020)	Page
• Added *Related MSP430 Circuits* section	1